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DEKORP- EUROPROBE-
Uralides Research Group

URSEIS

Transecting the Uralide Orogen

Database and State of the Art

Scientific Technical Report STR95/01

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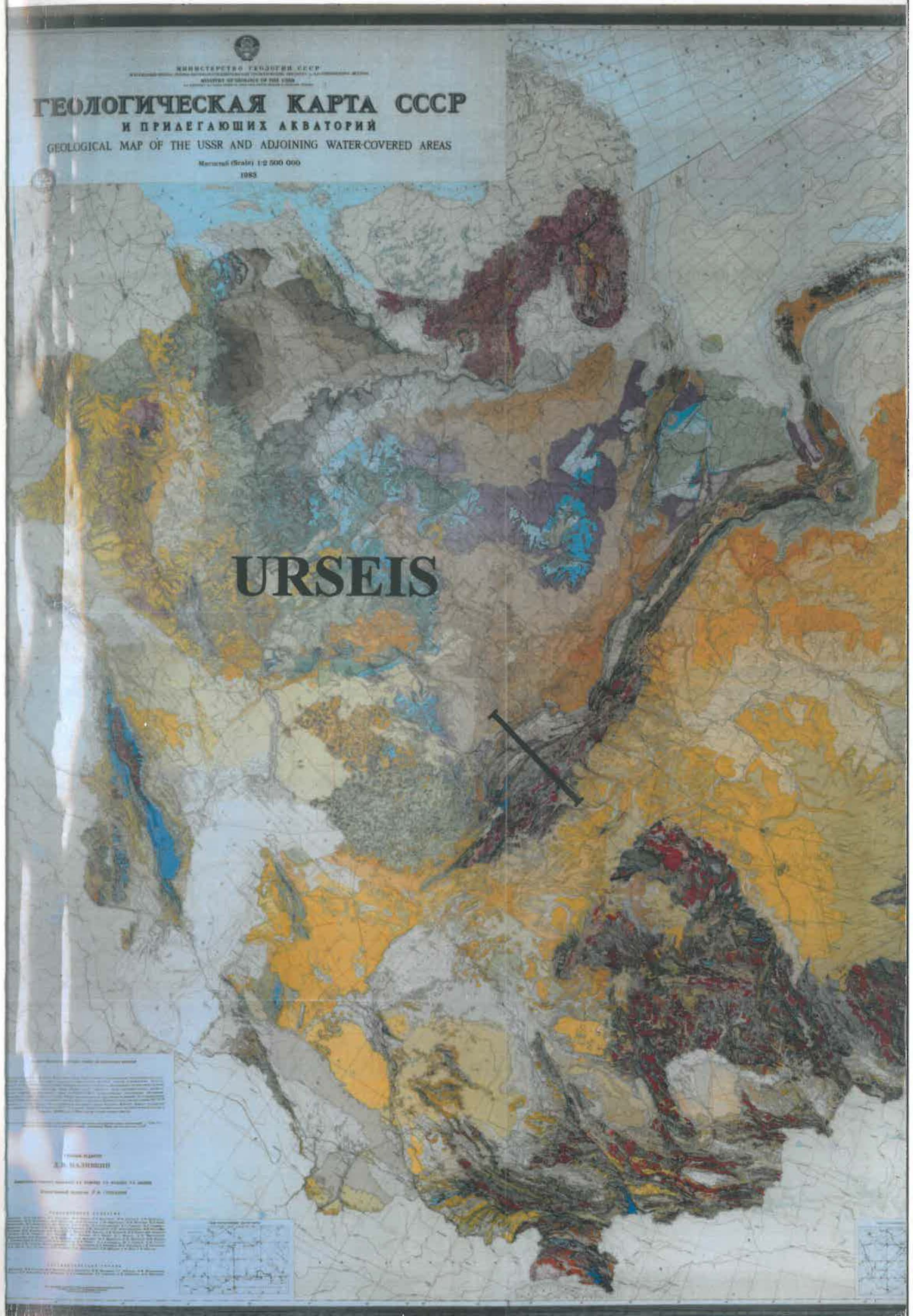

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Preface

This technical report has been initiated, compiled and edited until March 1994. Its objective was to collect the existing geoscientific database and state of the art on the Uralides. It serves as a platform for financial and operational decisions by national and international funding agencies on the URSEIS95-project (Urals Reflection Seismic Experiment and Integrated Studies) under the EUROPROBE umbrella.

The German DEKORP2000 (GFZ Potsdam), funded by BMBF, decided to operate this project in June 1994. Until November 1994, the COCORP project (Cornell University, U.S.A.), funded by NSF, and CICYT (Barcelona, Spain) got funding to join a western consortium on the operation of URSEIS in 1995. Until the end of 1994, a Russian consortium, funded by ROSGEOLCOM, was built under the leadership of SPETSGEOFISIKA (Moscow), integrating the BAZHENOV Geophysical Expedition (Sheelite, Ekaterinburg), BASHNEFTEGEOFISIKA (Ufa) and the GEON institute (Moscow).

All partners in the project join forces in financing, acquisition, processing, interpretation and publishing the results of the seismic experiment. The field parameters of the experiment (chapter VI) have been slightly modified in the meantime and include the Vibroseis source technique. The field campaign is scheduled for May-September 1995. The interdisciplinary studies (chapter VII) have been approved by the E.C. in the frame of the INTAS-programme (International Association for the Promotion of Cooperation with Scientists from the Independent States of the Former Soviet Union) in October 1994 and started their operational phase.

DEKORP-EUROPROBE-Uralides Research Group — Potsdam, January 1995

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Glossary

BGE	Bazhenov Geophysical Expedition, Sheelite (Department of UralGeolCom, Ekaterinburg)
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (German Geological Survey, Hannover)
BGS	British Geological Survey
BMFT	Bundesministerium für Forschung und Technologie (Federal Ministery for Research and Technology, Germany)
CDP	Common Depth Point
CNRS	Centre Nationale de Recherche Scientifique (France)
COCORP	Continental Consortium of Reflection Profiling (U.S.A)
DEKORP	Deutsches Kontinentales Reflexionsseismisches Programm (Germany)
DFG	Deutsche Forschungsgemeinschaft (German Science Foundation)
DSS	Deep Seismic Sounding
ECORS	Etude Continentale par Reflection Sismique
EGT	European Geotraverse
ESF	European Science Foundation
ESRU	Swedish-Russian reflection profile in the Urals
GEON	Centre of Regional Geophysical and Geoecological Research
INSTOC	Institute of Studies of the Continents, Cornell University
INSU	Institut Nationale des Sciences de l'Univers
GFZ	GeoForschungsZentrum Potsdam, Germany
GPS	Global Positioning System
KTB	Kontinentales Tiefbohrprogramm (German Continental Deep Drilling Program)
MUF	Main Uralian Fault
NFP20	Nationales Forschungsprogramm 20 (Swiss Special Research Programm 20)
NIS	New Independent States
NRCS	National Research Council of Sweden
NSF	National Science Foundation (U.S.A.)
PNE	Peacefull Nuclear Explosions
RAS	Russian Academy of Sciences
ROSGEOLCOM	Russian Geological Committee
TWT	Two-Way Traveltime
URALGEOLCOM	Uralian Geological Committee
U.K.	United Kingdom
UWARS	Ural Wide-Angle Reflection Seismics, 1992

Executive Summary

Objectives

The study of the Urals forms a key project of EUROPROBE, an ESF scientific programme, designed to unravel the tectonic evolution of Europe. EUROPROBE is building on the co-operation between geoscientists from eastern and western countries, it is a multidisciplinary program to address the crustal structure and orogenic evolution of the Uralide orogen. A key element is the acquisition of a modern, multichannel deep seismic reflection profile across the orogen, complemented by seismic wide-angle and other special measurements. The geophysical and geological problems to be studied by EUROPROBE in the Urals include: structure of the Urals at crustal and lithospheric scale and tectonic evolution, drift history of the continents involved in the collision, evolution of the root, neotectonics.

The Uralide orogen was formed at the eastern margin of the East-European craton between Cambrian and Permo-Triassic times with a complex accretionary history including ocean formation, oceanic subduction and volcanic arc building, obduction of oceanic crust and final collision of arcs and micro-continents. The Urals are central to our understanding of Paleozoic lithospheric dynamics and provide an exceptional opportunity to test alternative concepts of orogenic evolution. In spite of the striking similarities with the Appalachians, Caledonides and the Variscides, the Urals are distinct from other Paleozoic orogenic belts in a number of important aspects. Uralian features of special interest are: (1) the existence of a crustal root that reaches down to 60 km; (2) the extremely low terrestrial heat flow which represents a unique feature in the world (3) the preservation of ophiolites and volcanic-arc assemblages, and their associated ore deposits; (4) the preservation of high P - low T (glaucophane schist facies) and high P - high T (eclogite facies) metamorphic rocks along a suture zone some 2000 km long; (5) the existence of foreland and hinterland basins (including the Timan-Pechora and West Siberian) that contain some of the world´s largest hydrocarbon reserves; (6) the apparent subordinate role of syn- or -post-collisional collapse. Along with these pecularities, the Urals also contain the largest variety of metallic and non metallic ore bodies of the world.

The proposed deep seismic profile will image the structure of the orogen, help to unravel the tectonic evolution and discriminate between different tectonic models. The geometry of the crustal architecture is the primary input to quantify orogenic processes and to restore the crustal pathways. The objectives of the proposed project is to unravel the structural geology and tectonic models by imaging of (1) the crustal root, (2) the Main Uralian Fault and crustal shear zones, (3) magmatic bodies in the Hinterland, (4) the East-Uralian/Trans-Uralian Fault, (5) the East-European craton and Foreland basins, (6) Mantle structures, (7) Recent Tectonics and seismicity and (9) the gravity, geomagnetic and geoelectric anomalies of the crust.

Initial Studies

The existing geological and geophysical data relevant to the Urals and adjacent areas were reviewed at two EUROPROBE workshops jointly by groups of western and eastern experts: Sheelite/Zarechny (near Ekaterinburg), May 6-12th, 1992 and Oviedo (Spain), March 7-16th, 1993. Massive data exchange evolved from these workshops, in particular with respect to geological mapping and existing seismic datasets.

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The Urals were the site of extensive deep refraction profiling by the N.I.S. institutions in the past. The Urals were also selected for one site (SG-4) of the Superdeep Drilling Program of the N.I.S.

A teleseismic experiment (UWARS92) including controlled off-line source shotpoints on a 600 km long line across the middle Urals was performed in 1992 by the University of Grenoble, the GEON centre Moscow and the Bazhenov Geophysical Expedition (BGE) Sheelite. The data confirmed the existence of the crustal root beneath the Urals.

Reprocessing of selected seismic reflection lines has already been performed by the universities of Uppsala and Cornell with positive results.

The Bazhenov Geophysical Expedition in Sheelite and the GEON centre in Moscow were equipped in 1993 with modern seismic processing facilities by the University of Karlsruhe and the GeoForschungsZentrum Potsdam for future field quality control and data exchange, and for digitization, processing and archiving of superlong-range profiles (PNE), respectively.

A 60-km-long reflection line (ESRU93) was acquired close to the Superdeep Drilling Site SG-4 in 1993 by the Uppsala University and by the Bazhenov Geophysical Expedition. The Main Uralian Fault and the foreland thrust belt were clearly imaged down to 10 km depth.

Joint geological investigations are in progress by the GeoForschungsZentrum Potsdam and other European partners, UralGeolCom and the Urals branch of the Russian Academy of Science. Petrologists from Oviedo and Granada have been involved in collaborative research with petrologists from Ekaterinburg since 1987. Others, involving West-European and Russian institutions are in the planning phase.

Organization

Discussions between eastern and western scientists concentrated on two transects crossing the Ural Mountains in E-W direction. The present program is concentrated towards the Southern Urals at latitude 53° (referred to as the Southern Transect), near Magnitogorsk. The framework of this EUROPROBE venture will consist of a number of nationally and internationally operated and financed projects, in close partnership with corresponding N.I.S. institutions. EUROPROBE, represented by the URAL working group, will coordinate these contributions.

The DEKORP and the COCORP programmes are suggested to be the major contributors, which will focus on the southern transect. It is expected that DEKORP-COCORP will be responsible for field acquisition and data processing of the 500-km-long near-vertical reflection profile. Field acquisition will be performed by a commercial contractor, preferrably by a joint East-West venture using state-of-the-art techniques , selected after calling for tenders.

Complementary measurements (piggy-back experiments, e.g. wide-angle profiling for velocity control, crossline measurements for 3D control, three-component measurements for shear-wave studies, geological studies) will be conducted by different research groups, e.g. the Universities of Uppsala, Cornell, Karlsruhe, Glasgow, Grenoble, Oviedo, the GFZ Potsdam, the GEON centre Moscow, the BGE Sheelite. It is suggested that these research groups apply for at their corresponding national funding agencies. Furthermore, in order to continue the survey initiated by the Uppsala and Sheelite groups in 1993, individual contributions also

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include seismic measurements and other activities on the Northern Transect (58°) across the superdeep drillsite SG-4.

Summary

The Ural Mountains of central Russia separate the ancient core of Europe, the East European Craton, from the more easterly terranes of Siberia and Kazahkstan. Together with the Caledonian, Appalachian and Variscian orogenic belts, the Urals compose the Paleozoic framework of the old craton. Todays Mountains are largely a Tertiary feature. The Uralide orogen extends far eastwards, forming the basement of the Mesozoic hydrocarbon bearing formations of the West Siberian Basin.

The 3000 km long mountain belt is a unique natural laboratory with many key features that are important for our understanding of Paleozoic collisional orogeny. Comparison of the Uralides with the other related Paleozoic orogens will provide new insight into the processes of pre-Mesozoic plate tectonics. The existing database indicates the Urals are remarkable for their preservation of a continental root, the orogen having apparently suffered less post-orogenic collapse than most other Paleozoic mountain belts. Nevertheless, extension must have contributed significantly to the preservation throughout the belt of some of the world´s most complete ophiolites and island-arc volcanic suites (along with associated mineralizations), juxtaposed over very high-P blueschists and eclogites.

Other Paleozoic orogens have been re-equilibrated to normal crustal thicknesses during late- to post-orogenic processes. Such mechanisms of uplift and extension are also demonstrated in young orogens (e.g. Himalaya, Alps). The existence or appearant preservation of a thickened crust beneath the Uralides represents a fundamental problem in the understanding of orogenic processes.

The young history of the Urals, following extensive Mesozoic transgression and erosion, is of particular interest in view of the reportedly high (2mm/yr) uplift rates and widespread evidence of Tertiary (Recent?) tectonism. Historical seismicity is reported to be concentrated to the Middle Urals, apparently related to a compressional stress regime. Establishing the relationship of the crustal roots to deep structures in the subcrustal lithosphere and asthenosphere and understanding the development of these major structures in time is fundamental for full interpretations of the dynamic evolution of the Urals.

A wide range of new interdisciplinary investigations of the Uralide orogen are proposed here in the form of a collaborative European-American initiative, the scope of which has never been previously attempted for the continental lithosphere. Geoscientists from institutions all over Europe will work together with N.I.S. colleagues on key aspects of the mountain belt. COCORP-DEKORP type deep seismic reflection (CDP) profiles across the Southern Urals are a key experiment for relating shallow to deep structures.

I Introduction

The Uralide Orogen at the border between Europe from Asia, separating the ancient Archean and Proterozoic crystalline basement of the East European craton from the Paleozoic terranes of Western Siberia and Kazakhstan. It stretches from the high Arctic of Novaya Zemlya, 3000 km southwards to near the Aral Sea and then swings eastwards into the mountains of Tien Shan and western China. The long linear physical expression of the Ural Mountains results from Tertiary and Recent Uplift. This apparent simplicity masks a period of extensive peneplanation in the Mesozoic, including Cretaceous marine transgression; much of the previous complexity of Mid-Late Paleozoic collisional orogeny is hidden beneath the latter. The hinterland of the Uralides extends far eastwards into Asia, forming the basement to the vast hydrocarbon-bearing successions of the west Siberian Basin.

The Urals play an important role for our understanding of lithosphere dynamics in the Paleozoic. Together with the Caledonides in the northwest and the Variscides in the southwest, the Uralides frame the East European craton (Fig. 1). Paleozoic orogeny welded together the main structrual elements of the European lithosphere. The tectonic analyses of the Uralides, proposed here, will allow comparison with the Caledonian-Appalachian-Variscan system, throwing new light on processes of early-mid Phanerozoic plate tectonics.

The Urals are undoubtedly one of the best preserved Paleozoic orogens in the world. Whereas most others have been disrupted by Mesozoic extension and fragmented by the opening of younger ocean basins (e.g. in case of the Appalachians and Caledonides), the Uralides have remained intact. Various features are of particular interest. The orogen is remarkable for the preservation of ophiolites and volcanic island arc assemblages and their associated mineralization. The suture zone separating these eugeoclinal rocks from the margin of the East European craton is characterized by a belt some 2000 km in length where very high P/T (glaucophane schist - eclogite) metamorphic rocks are preserved. The foreland and hinterland basins contain some of the world´s largest hydrocarbon reserves.

The deep structure of the Urals is of particular interest. Several deep seismic sounding (DSS) profiles, crossing the orogen, provide evidence for the existence of a Moho depression down to 60 km (Fig.2). Its relative position with regard to the morphologic expression of the Urals is a key for further understanding. Heat flow is reported to be unusually low (<30 mW/m^2), supporting the concept of a thick, non-radiogenic anomalous Uralide lithosphere. The Moho root may be related to Paleozoic collision or Tertiary and Recent uplift or both. Neotectonic features are numerous: present uplift rates are estimated at 2 mm/year, with a concentration of historical seismicity in the Middle Urals (Ekaterinburg - Chelyabinsk areas).

Understanding of the orogen - its collisional history, Mesozoic erosion and Tertiary inversion depends fundamentally on our ability to relate upper crust to deep lithosphere structure, to analyze geological relationships at the surface and relate them to processes at depth.

This research proposal presents a variety of research targets that are central to our understanding of the Uralides. The structural analysis requires the application of deep reflection seismic profiling, using state-of-the-art technologies; this experiment provides the core of the Uralide program. Interpretation of lithosphere structure and its evolution in time will rest on a variety of other geological and geophysical investigations, complementary to the

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reflection seismic profiling. These are identified in this proposal as individual research objectives.

II Background

The evolution of orogenic processes is a key problem in geosciences. Combining geological studies of surface structures and deep reflection seismic profiling is essential for quantifying lithospheric processes by investigation of structures, physical properties and composition.

Developments within the former Soviet Union over the past five years have led to a new openness and enthusiasm on the part of N.I.S. scientists for collaboration with western colleagues. At the same time, we are faced with an unprecedented opportunity to integrate an entire continent, amounting for one sixth of the global continental landmass, into a modern plate tectonic context. Many geologic and tectonic features of the former Soviet Union are obvious targets for investigation, but the Ural Mountains, defining the boundary between the two main continental masses of the East European and the Siberian cratons, stand out as one of the most impressive tectonic elements of the continental interior.

The Uralide science plan, presented here, is a collaborative European-American initiative, on a scale never previously attempted for the continental lithosphere. The program has been defined at workshops and other meetings where N.I.S. scientists, american and european scientists have examined the existing Uralide database and planned the new work. Agreements on collaboration between EUROPROBE, INSTOC (Institute for the Study of the Continents), ROSGEOLCOM (Russian State Committee for Geology) and RAS (Russian Academy of Sciences) have provided the foundation for this new initiative.

Designing the new work involved analysis and reprocessing of specific sets of existing data, both geological and geophysical, and several bilateral and multinational programmes are underway, financed by national and international agencies (ESF, NSF,DFG, BMFT, COCORP, GFZ, INSU, NRCS). Geological field investigations, teleseismic measurements for studies on a lithospheric scale and a short seismic reflection profile in the Middle Urals, as well as reprocessing of previously acquired data have shown promising results (confirmation of the root, existence of large scale shear zones) and the need for a new large experiment.

Two EUROPROBE workshops, one in Sheelite (near Ekaterinburg, Russia) and the other in Perlora (near Oviedo, Spain) have been of particular importance, both sponsored by the European Science Foundation, through the EUROPROBE program. The meeting at Sheelite (May 1992) provided an extraordinary opportunity to examine and discuss the latest work on the orogen with experts in Geophysics, Geology and Petrology from the N.I.S. The information base today is broad and accessible. For instance, no orogen in the world is covered by potential field data (magnetic and gravity) in such detail as the Uralides: these data are essential for regional structural analysis. The collaborative program presented here is dependent for its success on the open exchange of existing data; this is now accomplished in the area of the experiment.

During the months following the Sheelite workshop Uralide experts augmented the general information base by preparing summaries of Uralide geology (Appendix A,B,C) and detailed compilations of southern and middle Urals transects. The second EUROPROBE workshop in Perlora (March 1993) analyzed this database in detail; the in-depth discussion that followed provided the basis for the formulation of the plans presented here.

Fig. 1: Sketch tectonic map of the continents in late Paleozoic time, showing the spatial relationship of Paleozoic orogens during formation of the Pangean supercontinent, and the location of the Ural Mountains in particular. Of these orogens, only the Urals have remained relatively intact, without subsequent rifting and development of an ocean basin (Matte, 1986).

Fig. 2: Crustal velocity section through the northern Urals as part of the QUARZ profile (T. Ryberg after Yegorkin and Mikhaltsev, 1990) using peaceful nuclear explosions and chemical explosions. Length of section is 1000 km.

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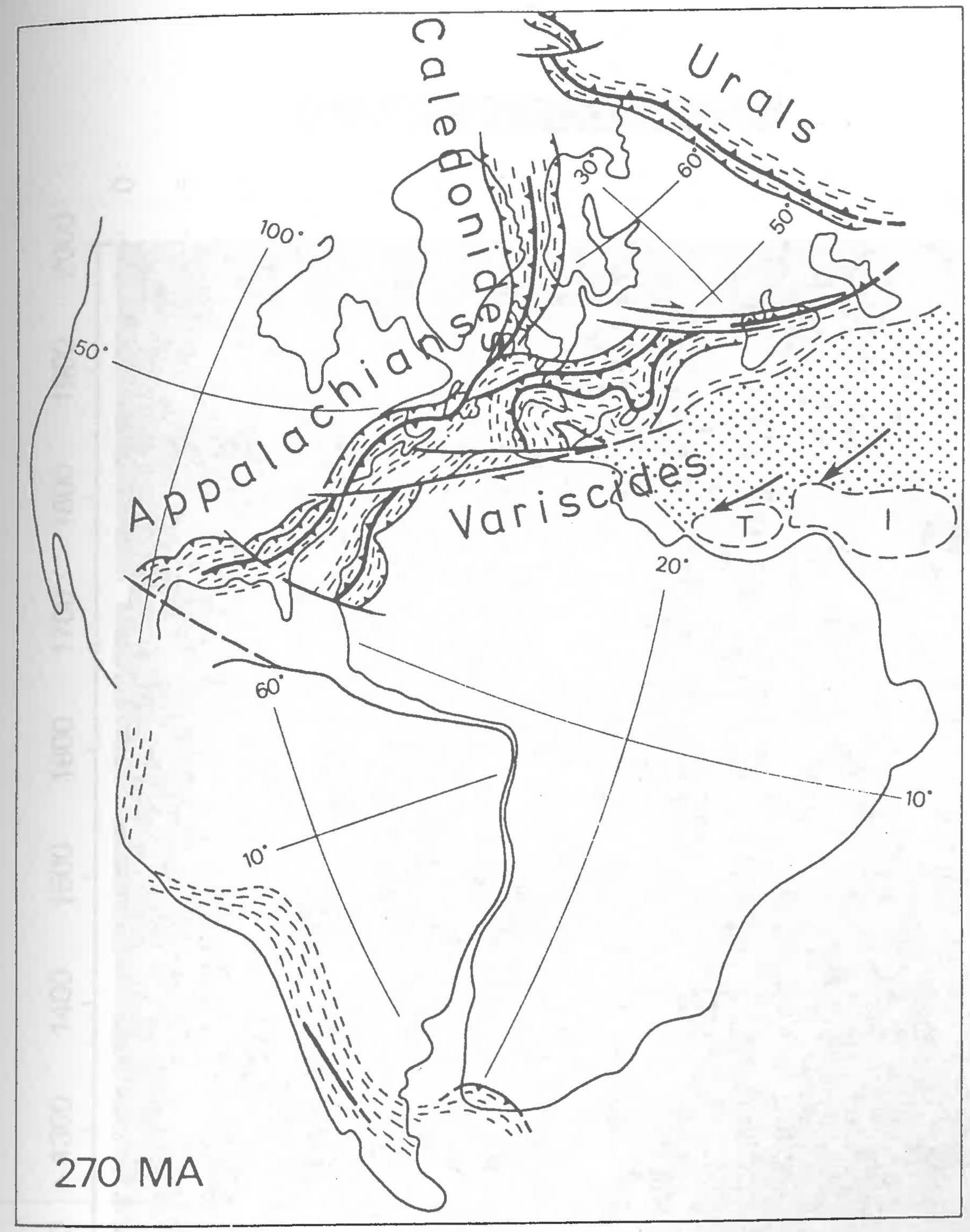

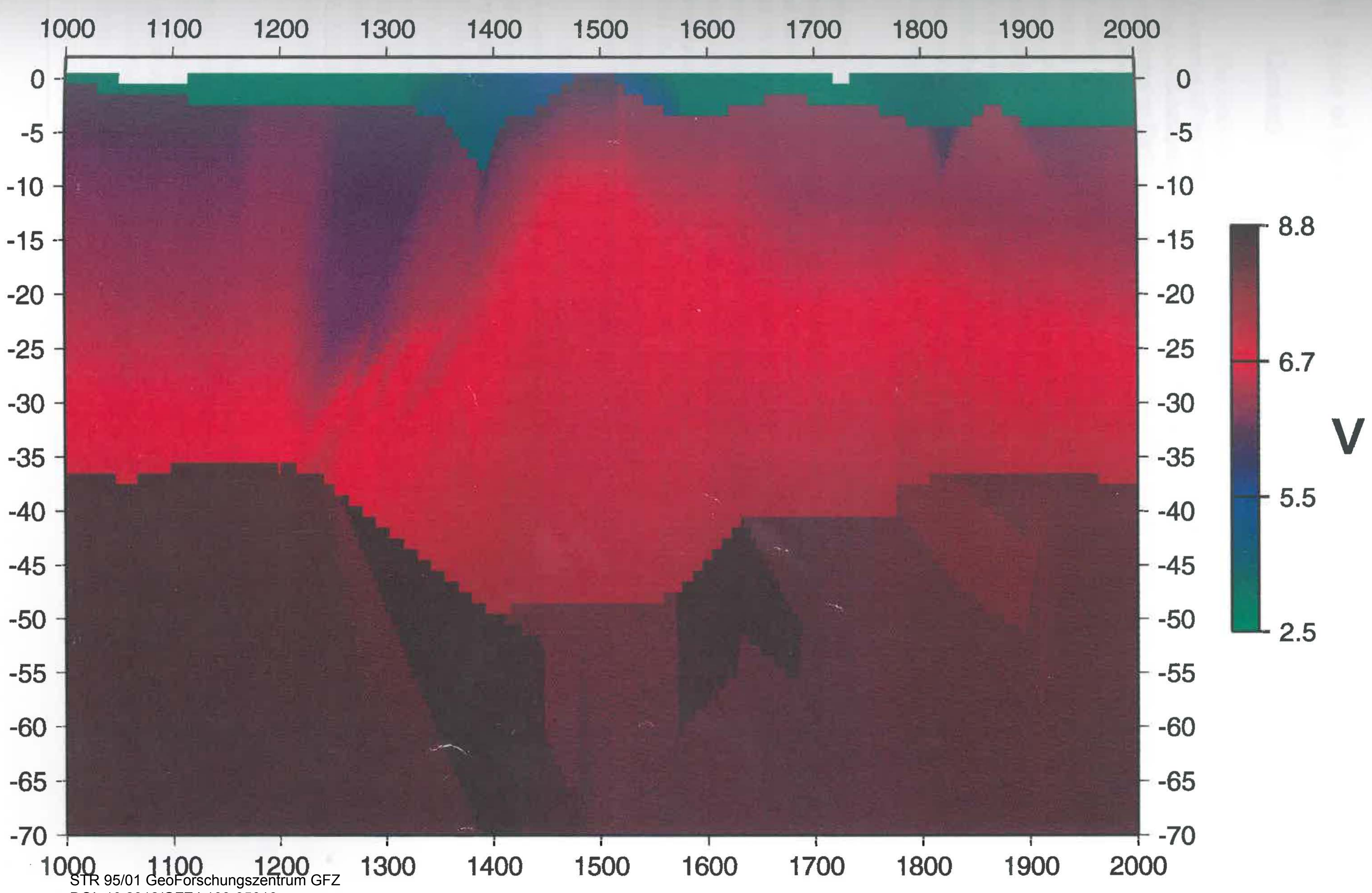

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III State of Knowledge

Geology

The Urals evolved as an orogenic belt through the Middle and Late Paleozoic, with culmination of the orogeny in late Permian time. The first plate-tectonic evolution began with rifting and development of a passive continental margin on the East European platform in latest Precambrian to Early Ordovician time (Hamilton, 1970; Ivanov et al., 1975, 1981, 1986; Zonenshain et al. 1990). According to these authors, Middle Paleozoic time was characterized by rifting of micro-continental fragments, formation of island arcs and back-arc basins, and accretion with westward vergency of these micro-continental and island arc terranes along the margin of the East European Craton. Early stages of subduction involved very high pressure metamorphism and obduction of Ordovician ophiolites. Final collision of this collage with the East European craton took place in late Carboniferous and Permian time, accompanied by the development of intra-montane and foreland basins and a classical foreland fold and thrust belt. The present geological mapping provides a sound basis for future field studies which will allow to distinguish between different tectonic models.

The gross structural configuration of the Ural Mountains is dominated by the 2000-km-long Main Uralian Fault (MUF, Fig. 3, 4, 5)), which trends north-south along much of the length of the orogen, and divides the range into an "external" zone to the west and an "internal" zone to the east. Within the external zone there are thrust sheets which carry basinal and shelfal deposits of the East European platform margin and underlying less allochthonous units, some incorporating crystalline basement. Associated with the Main Uralian Fault is an extensive assemblage of oceanic rocks accompanied by development of high-pressure, low-temperature metamorphic rocks of blueschist and eclogite facies. The internal parts of the Urals are characterized by a complex distribution of oceanic, island arc, and micro-continental fragments, a unique platin-rich belt, as well as by magmatic rocks of late Carboniferous age, intruded into this heterogeneous collage.

Most of the major geological units extend throughout the entire Urals in narrow, submeridional, regularly located stretches. The Uralian orogen has been traditionally subdivided into six longitudinal tectonic zones that are parallel to the former margin of the East European platform. From west to east these are: the Pre-Uralian Foredeep, the West Uralian Megazone, the Central Uralian Megazone, the Tagil-Magnitogorsk Zone, the East Uralian Zone, and the Trans Uralian Zone. The first three zones consist of autochthonous and parautochthonous units of the East European platform. The last three comprise oceanic and island arc terranes, or "exotic" tectonic elements within the eastern Urals. The Main Uralian Fault is the boundary between these two major groups of zones and constitutes the suture of the orogen. The general structure of the orogen has been described by: e.g
Kropotkin, 1967; Ivanov et al., 1975, 1985; Zonenshain et al., 1984, 1990; Khain, 1985; Puchkov, 1989.

The PreUralian Foredeep represents a huge foreland basin developed in the western part of the Uralian fold belt during late Carboniferous-Permian times. The earliest synorogenic sediments are of Lower-Middle Carboniferous age. Deformation within this zone is characterized by thin-skinned tectonics grading into undeformed foreland basin sediments towards the west. This foreland basin contains some of the largest oil and gas provinces in Russia.

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The West Uralian Megazone contains deformed sediments of Ordovician to Carboniferous age and their basement rocks of Proterozoic age that constituted the former East European platform during Paleozoic times. The continental slope and rise sediments are those of the Zilair-Lemova zone which are also included in this West Uralian Megazone. Thrust nappes, together with folds and related cleavages constitute the major structural features of this unit.

The Central Uralian Megazone contains mainly highly metamorphosed Precambrian rocks, both Archean and Proterozoic in age, sometimes reaching granulite facies. Several stages of deformation and metamorphism have been recognized in this zone and produced pervasive tectonic fabrics. Some of the deformation stages are of Precambrian age.

The Main Uralian Fault extends for more than 2,000 km along most of the length of the Urals, and constitutes the main tectonic boundary between the East European platform (Central Uralian Zone) and the Uralian paleo-ocean (Tagil-Magnitogorsk Zone). This fault zone can be traced at the surface by bands of serpentinitic melanges hundreds of kilometers long, although it varies in character along strike. It dips at moderate to steep angles eastwards along the entire western margin of the Urals; shallow reflection profiling has shown it to extend to at least 7 km depth and the more recent ESRU project to 10 km. Structural and kinematic data are lacking for this fault as well as for most of the other structural features in the Urals. Age constraints on the timing of deformation of the Main Uralian Fault are at present relatively poor. The youngest rocks involved in this fault are of lower Carboniferous age in the northern part of the Southern Urals. In the southernmost Urals, Jurassic and early Cretaceous sediments there are some of the oldest rocks to overlap the Main Uralian Fault, placing an upper limit on the age of deformation in this area.

The Tagil-Magnitogorsk Zone, to the east of the Main Uralian Fault, comprises mostly ophiolites and island-arc complexes. The Ordovician ophiolites of the Tagil portion of this zone are characterized by a sheeted dyke complex, tholeiitic pillow lavas accompanied by thin jasper layers, and thick sections of island-arc volcanic rocks, composed mostly of andesitic tuffs. The ophiolites of Magnitogrosk are of Early Devonian age and have the same characteristics as those of the Tagil portion (Ivanov and Ivanov, 1991). These ophiolite sequences are some of the most complete and well-preserved in the world. According to both geological and geophysical data, this zone represents a preserved remnant of oceanic crust more than 1000 km in length. The Tagil-Magnitogorsk Zone is also characterized by low heat flow (25-30 mW/m^2; V. Cermak, pers. comm.) and a notable absence of granitic and Precambrian continental crust. The Uralian Superdeep borehole (targeted for 15 km and presently at 4.6 km depth) is being drilled in the western part of the Tagil-Magnitogorsk Zone.

The East Uralian Zone is formed by a collage of micro-continental and oceanic assemblages. Granitoids and gneisses are juxtaposed with Ordovician and Carboniferous sediments. Ophiolite suites and volcanic and volcanoclastic rocks of island-arc affinities, Ordovician to Devonian in age, are characteristic in this zone. This entire complex was intruded by granitic rocks during Late Paleozoic times.

The Trans-Uralian Zone is covered by Mesozoic-Cenozoic sediments of the West Siberian basin, sediments and volcanic rocks of Carboniferous age are found in drill cores. A narrow zone with high-pressure metamorphic assemblages is present in the easternmost area suggesting a west-dipping suture zone.

The Ural Mountains are unique in the world for the widespread occurrence and preservation of high-pressure metamorphic assemblages. Blueschist and eclogite facies rocks are linearly distributed over 2,000 km along strike, primarily in association with the Main

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Uralian Fault (Sobolev, et al. 1986; Puchkov, 1989). This high-pressure metamorphism is found to affect rocks of both oceanic and continental crust. Both Precambrian and Paleozoic ages have been proposed for this high pressure event.

The metamorphic history of the Central Uralian Megazone records pre-Uralian events. Relicts of granulite facies metamorphism, with ages of 2,600 +/- 100 Ma, are recorded in rocks of the Taratash and Seliankinsky massifs. Rocks of amphibolite facies yield ages between 2300-1650 Ma from the Alexandrovsky, Taratash, and Kharbey massifs (Ivanov et al., 1985).

This regional metamorphism at amphibolite to granulite facies is characteristic of the crystalline basement of the East European Platform. Later phases of metamorphism are dominantly retrograde in character, and are characterized by the development of strong fabrics. Glaucophane and glaucophane-eclogite schists can be traced discontinuously in the footwall of the Main Uralian Fault throughout the length of the belt. Glaucophane is observed in rocks of various composition and age, and is associated with lawsonite, stilpnomelane, phengite, biotite, and garnet. The age of blue schist facies metamorphism in the Central Uralian Megazone is probably Middle Paleozoic (Lennykh, 1980; Ivanov, 1981; Matte et al., 1993) and related to the early orogenic obduction of Ordovician ophiolites onto the margin of the East European Platform. Understanding this early orogenic processes along the Main Uralian Fault is fundamental for all reconstructions of subsequent collisional processes.

The Ural orogen is notable for the size and extent of preservation of ophiolites and island arc terranes which were accreted during the final stages of collision. These island arc complexes make up the axial part of the Tagil and Magnitogorsk zones, and are interpreted as tectonic elements which developed in the Uralian paleo-ocean. The eastern part of these terranes is overlapped by Mesozoic and Cenozoic deposits of the West Siberian Basin, and to the south, the Magnitogorsk zone probably extends in the subsurface into the Kazakhstan and Tien-Shan systems of central Asia.

Orogenic Evolution

Structures of the Urals were generated during Paleozoic. The complex crustal evolution comprises margin rifting, ocean floor spreading, subduction and building of island arcs (Ordovician until Devonian) as well as obduction and collision with the European platform, finally the accretion of island arcs and micro-continents (400-250 my). Alternatively, models of in-situ evolution are in discussion. First plate-tectonic models with contradictory polarities were presented by Hamilton (1970), Ivanov et al. (1975) (Fig.6) and Zonenshain et al. (1984) (Fig. 7).

The evolution started with riftogenic processes (Ivanov et al., 1984) affecting the East European continent in the process of mantle diapir upwelling. Further development of the process led to rifting of the continental crust. In the late Arenigian, the epicontinental rifting was changed to seafloor spreading. The Tagil-Prisakmara subocenanic zone formed, its relics represented by sodic tholeiite basalts and cherts of Akay, Surgrula, Polyakovka and other suites, basalts of the western part of the Tagil Zone, as well as by mafic and ultramafic plutonic bodies connected with them. In the later half of the Ordovician, the riftogenesis-spreading axis shifted to the east, which probably resulted in formation of the Denisovka oceanic basin and Mugodzhary microcontinent. Simultaneously, the Tagil-Prisakmarian zone experienced subduction and formation of an island arc, which led to the formation of andesitic magmatism and associated pyritic deposits which are now exposed in the Blyava synform of the Southern

Urals. This subduction zone probably died out in the Early Silurian, and a new one formed in the Denisovka oceanic basin. Its relics have been found as allochthons on the East Mugodzhary block, in the synform structure of the southern end of the eastern Uralian volcanogenic zone.

By the beginning of the Middle Devonian, the development of the subduction zone had led to the closure of the Denisovka oceanic basin; the Kazakhstanian continent had accreted at the expense of newly formed crust and the Mugozharian micro-continent. The subduction zone jumped to a new place, forming the Magnitogorskian zone. An island arc and back-arc basin had been formed (Irendyk, Karamalytash, Mugodzhary, and other volcanic formations). In the Late Devonian, the subduction zone shifted under the margin of the Kazakhstanian continent; an Andean-type active continental margin formed, with volcano-plutonic belts of calc-alkaline composition along its margin. By the Middle Carboniferous, all of the oceanic crust had been subducted under the Kazakhstanian continent, bringing to an end the formation of the volcano-plutonic belts and resulting in a collision of the Kazakhstanian and Euramerican continents. The collision was accompanied by a multifold stacking of crust, folding, ad thrusting, generation of palingenetic granites (Samarkin and Samarkina, 1988), mountain building, and formation of the PreUralian foredeep.

Consideration of the Urals as largely "uncollapsed" orogen from Late Paleozoic time until now challanges fundamental aspects of orogenic processes. Current models of Phanerozoic orogens suggest that thickened continental crust, resulting from continental collision, is inherently weak and unstable, leading to the eventual re-equilibration (collapse) of the orogenic crust. Many examples can be cited of mountain belts which are experiencing or did undergo late- to post-orogenic collapse (Appalachians, Caledonides, Variscides, Himalayas, Alps, etc.). These effects are manifested in surface exposures of large extensional faults, associated sedimentary basins, exposures of high-grade metamorphic rocks within internal portions of the orogens, as well as relatively thinned continental crust (30-35 km), and significant lower crustal reflectivity which has often been attributed in some way to the extensional processes at depth. In contrast, several examples can be cited of Precambrian orogenic belts which appear to remain as fossilized collisional zones.

Fig. 3: Tectono-lithostratigraphic map and zonation of the Ural Mountains (modified after Ivanov et al., 1975)

Fig. 4: Extract of the geological map of the Urals, here southern Urals. Original is at the scale of 1:1.500000, here reduced by 71 %. The dashed lines mark the possible location of the seismic profile. Magnitogorsk in the centre of the map.

Fig. 5: Geological cross section through the Southern Urals, from the 1:1.500000 tectonic map.

Fig. 6: Plate-tectonic evolution of the Southern Ural Mountains in the Paleozoic (Ivanov et al., 1975)

Fig. 7: Plate-tectonic evolution of the Southern Ural Mountains in the Paleozoic (Zonenshain et al., 1984)

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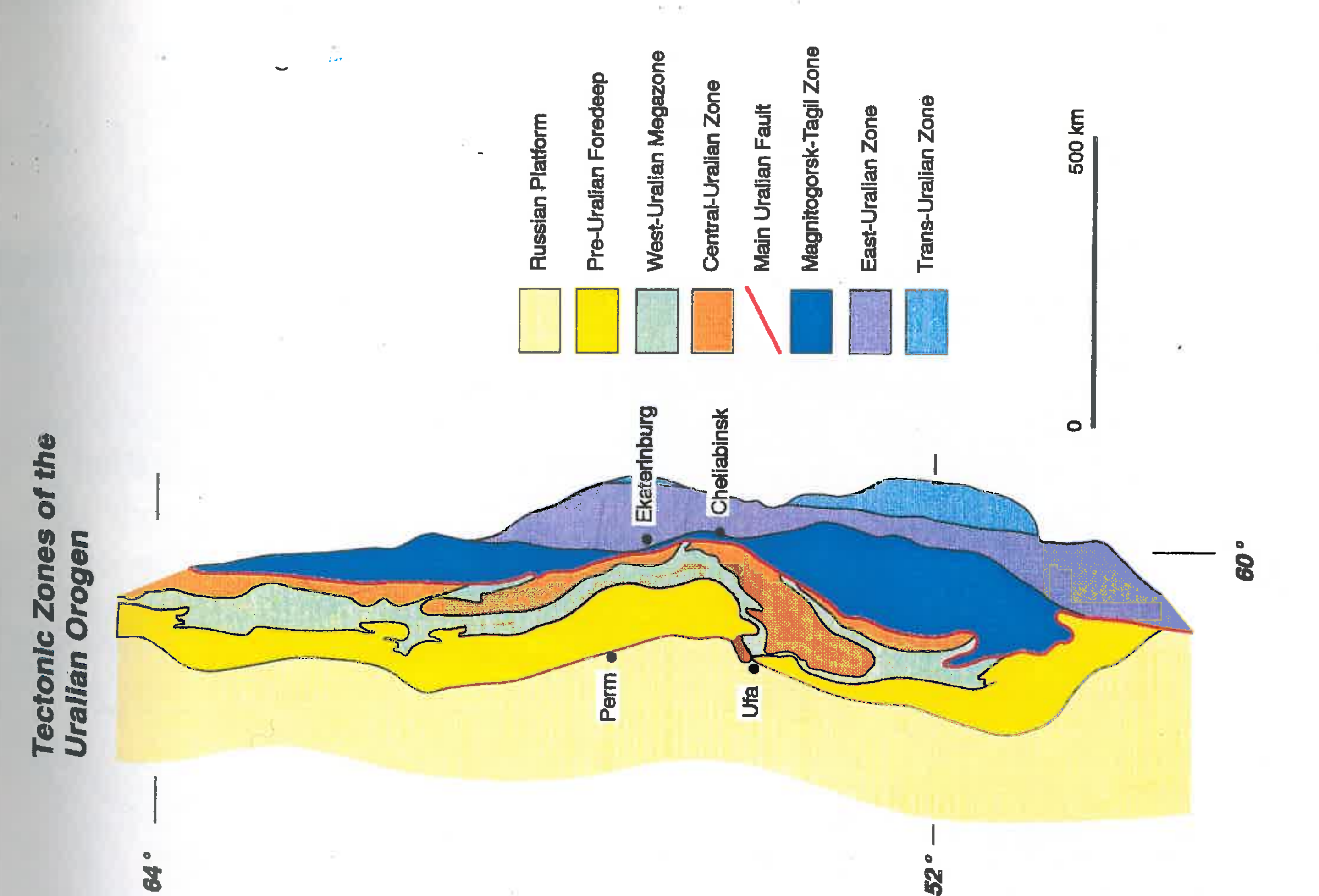

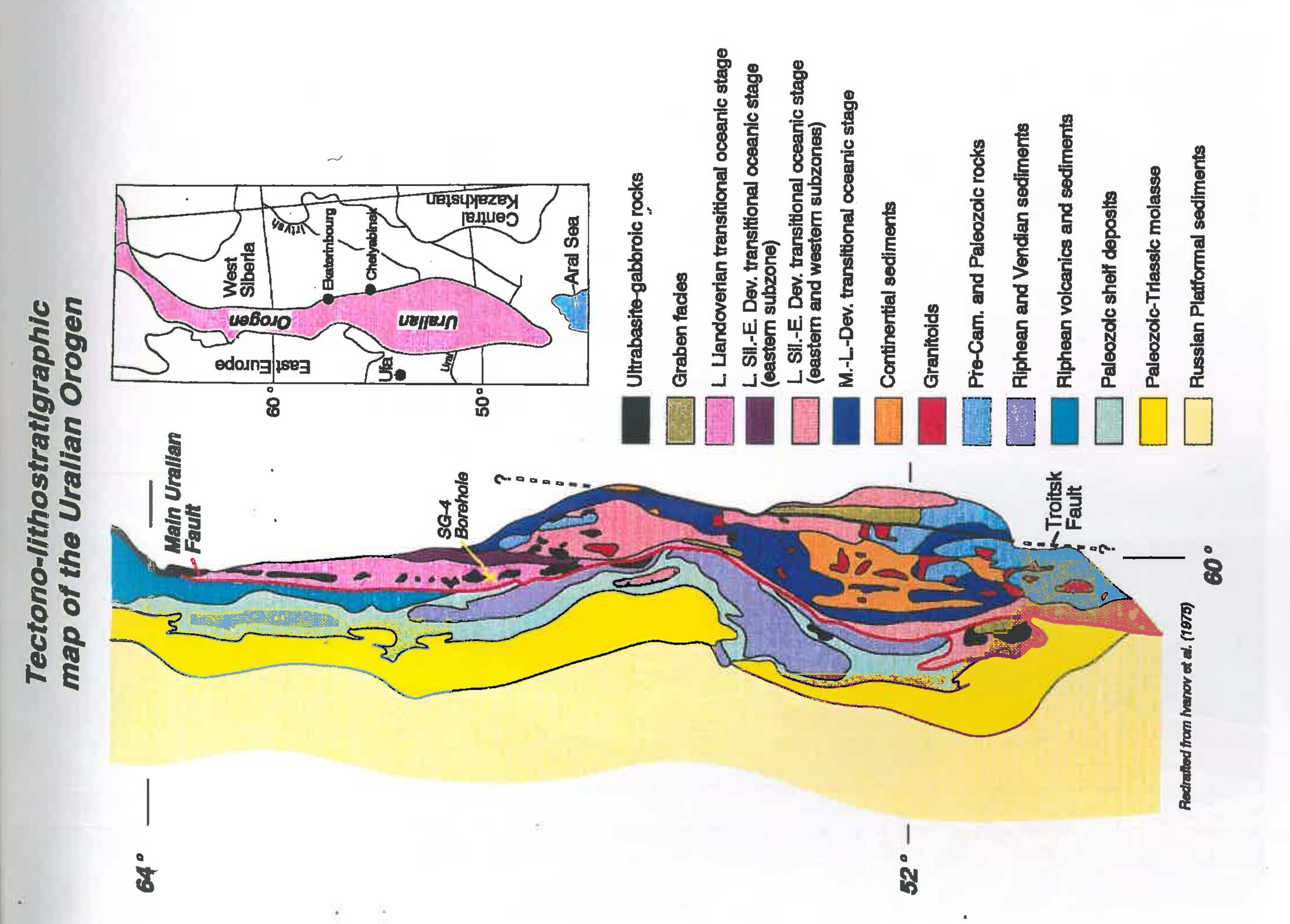

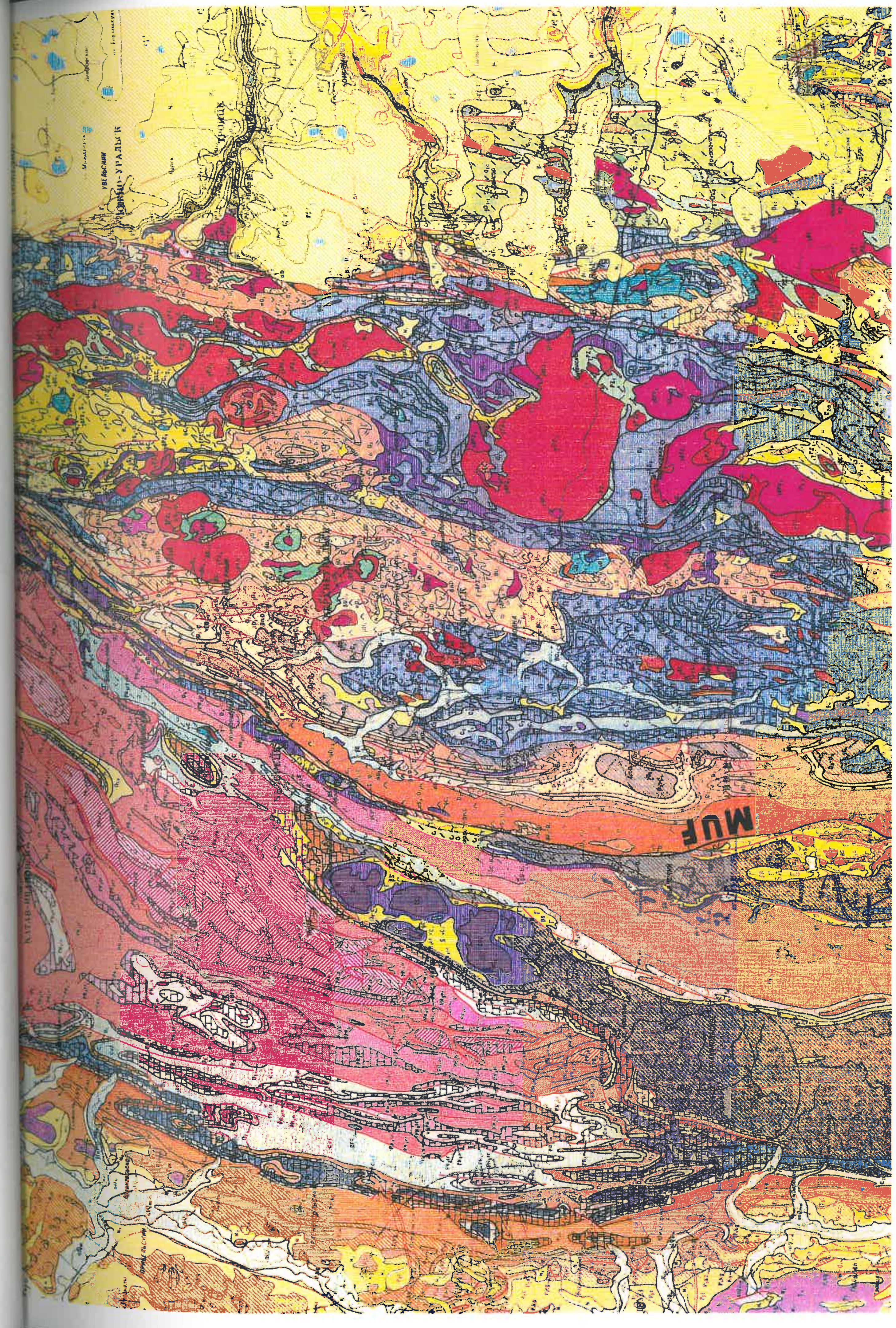

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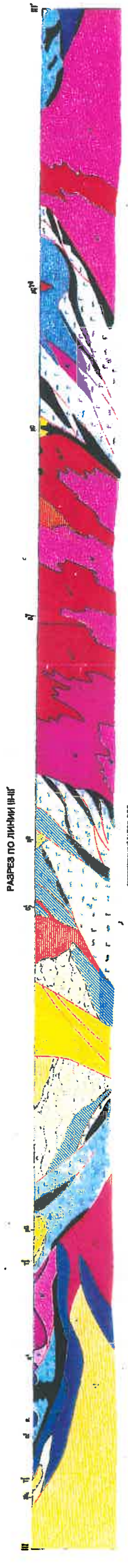
РАЗРЕЗ ПО ЛИНИИ II-II'

Масштаб горизонтальный и вертикальный 1:500 000

РАЗРЕЗ ПО ЛИНИИ I-I'

Масштаб горизонтальный и вертикальный 1:500 000



РАЗРЕЗ ПО ЛИНИИ III-III'

Масштабы горизонтальный 1:500 000
вертикальный 1:100 000

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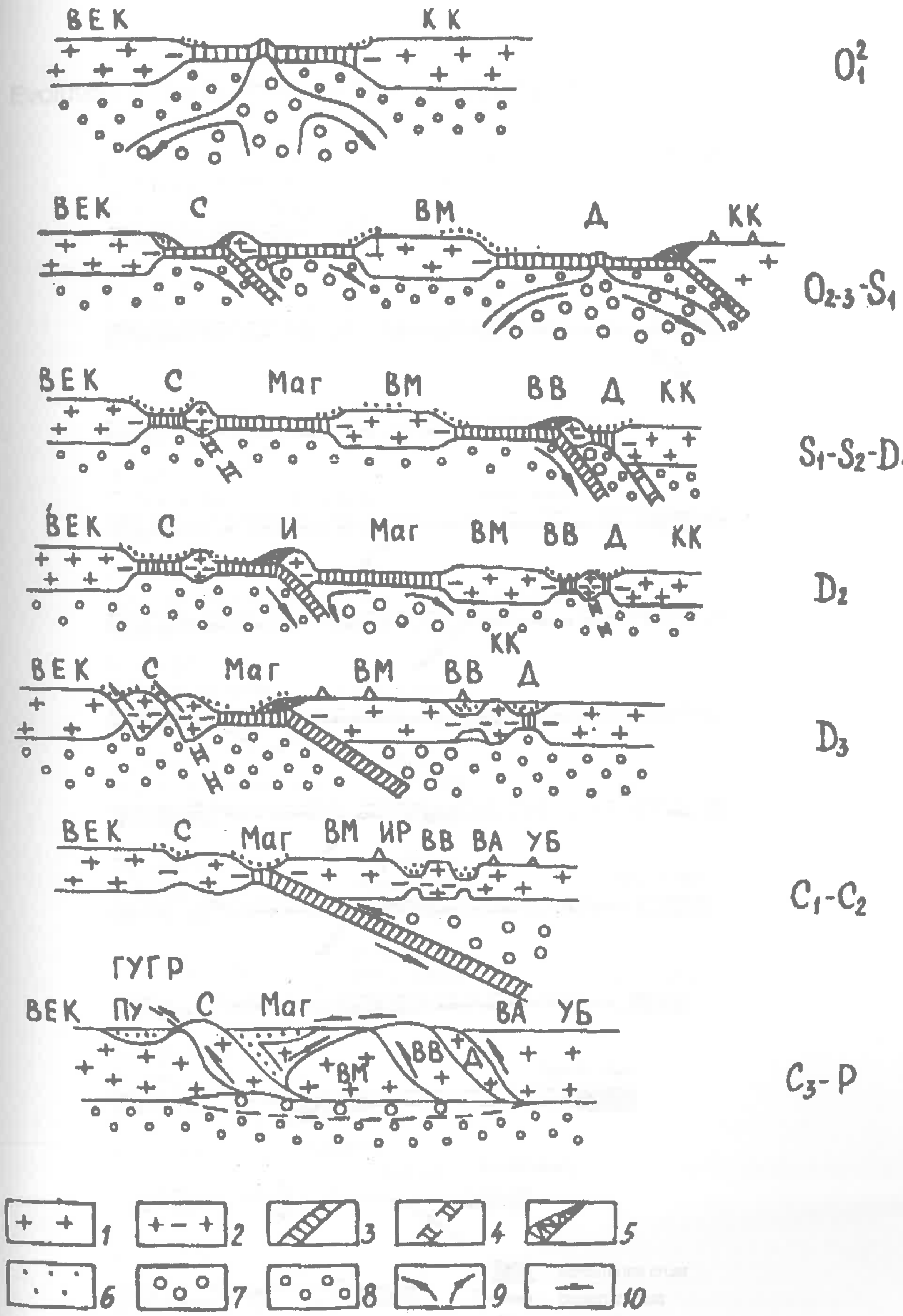

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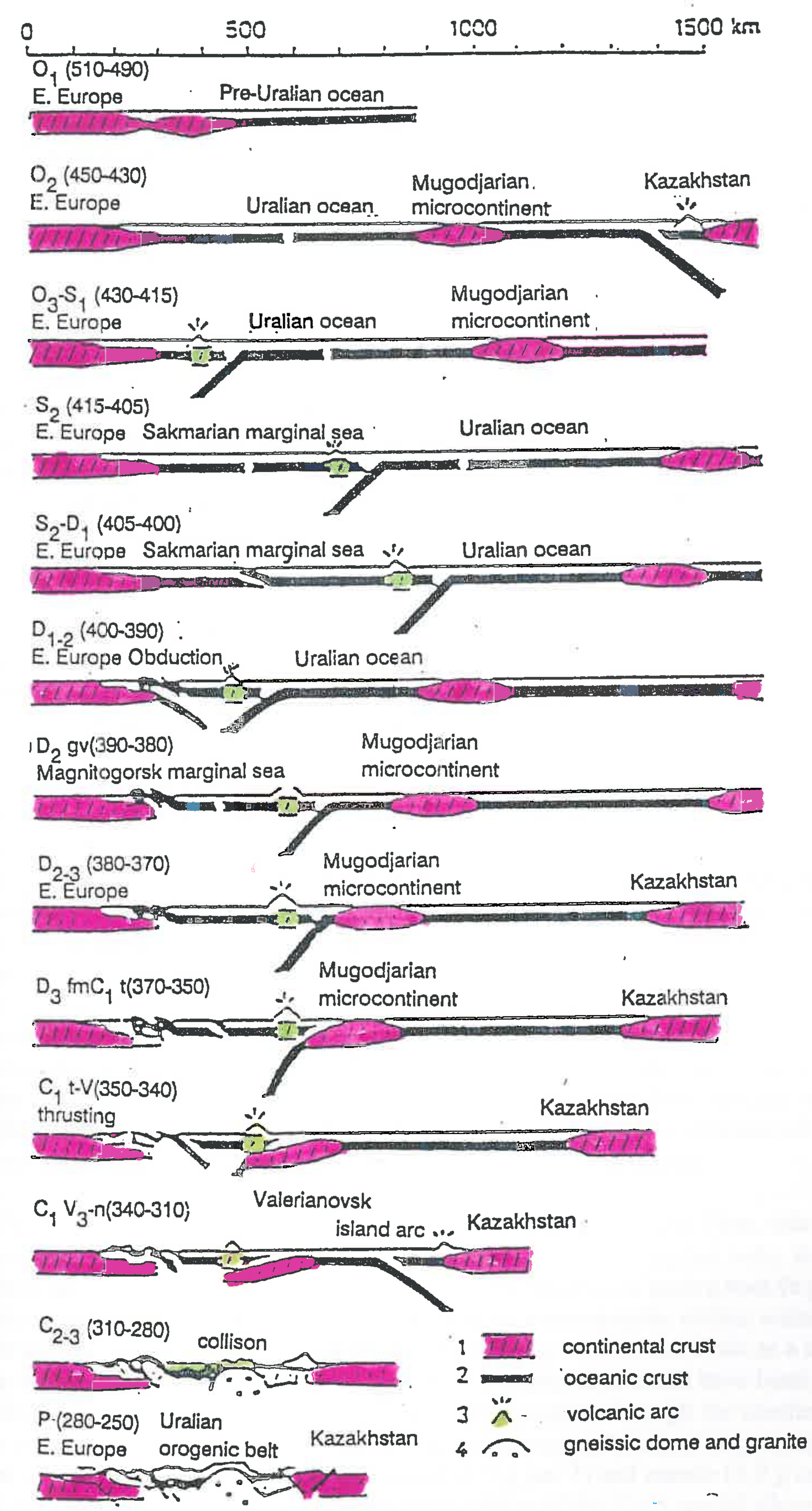
Evolution of the Southern Urals in the Paleozoic



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Crustal Structure from Deep Seismic Sounding

Investigations of deep structure are primarily based on several Deep Seismic Sounding (DSS) profiles (c. 8000 km) and a variety of shallow (down to 6 sec TWT) reflection lines (c. 3000 km). Figure 8 shows DSS (long-range refraction wide-angle reflection measurements) which have been collected mostly by UralGeolCom (Ekaterinburg) and its subsidary department Bazhenov Geophysical Expedition (BGE, Sheelite) during the last two decades. The GEON centre (Moscow) collected superlong-range refraction profiles using Peaceful Nuclear Explosions (PNE) as sources for observations up to 4000 km distance. One such profile crosses the Urals (QUARZ, figs. 2, 8). In addition to P-wave velocity sections, S-wave velocity sections (through observations by three components) have been constructed which led to mapping of the Moho depth and the crustal `maficity´ (derived from P- and S-wave velocity models). Shallow reflection profiling using the CMP technique (e.g 12- or 24 fold coverage) was done by BGE on short selected lines in the Urals in the context of mineral exploration, as well as by other institutions in the context of the oil and gas exploration east and west of the Urals. In Appendix A a location map of all existing seismic lines and a table of recording parameters is presented. The DSS data were collected primarily by GEON and the BGE in analog form. There is currently an agreement between UralGeolCom and the GeoForschungsZentrum in Potsdam and the Geophysical Institute in Karlsruhe which make these data available to EUROPROBE researchers. Digitization hardware and software have been installed at GEON and the BGE to facilitate the transfer of the data to standard international formats.

One of the crucial and yet disputable features of the Urals is the presence, location, shape, composition and origin of a significant crustal root beneath the orogen as derived from seismic data from Russian DSS and refraction studies. Interpretation of DSS data show a Moho which is about 10 to 15 km deeper below the Urals (Figs.2, 9) than below the East European Platform to the west and the West Siberian Basin to the east (Yegorkin and Mikhaltsev, 1990; Ryalka et al, 1992, pers. comm.). The width of this root into the mantle appears to be generally about 100-200 km, containing high velocity material of 7.2-7.8 km/s in the lowermost 20 km (Rhizhy et al., 1992). The mantle velocity below the Urals is variable with velocities in the range of 8.0-8.5 km/s. The crust above the anomalous deep crust is of higher density (+0.1-0.15 g cm^{-3}) and higher velocity (+0.3-0.5 km/s) than the adjacent areas. A map of the Moho topography based on DSS and refraction data is presented Fig. 9 indicating a pronounced crustal root on the order of 50-65 km running the length of the orogen along the central axis (Rybalka et al., 1992, Appendix B). This root is coincident with a pronounced linear Bouguer gravity anomaly (see Appendix B). Figures 10 and 11 show examples of interpretation of a DSS profile crossing the middle Urals, collected by BGE. Numerous reflecting horizons appear within the whole crust on the DSS sections which have been attributed to shear zones. Typical for all the interpretations is the presence of vertical shear zones which penetrate the entire crust down to and into the mantle.

The significance of the crustal root is striking in several respects. First, this crustal thickness appears anomalous in comparison with other Paleozoic orogenic belts. Both the Appalachian and Variscan belts are marked by a notable absence of such a root (e.g., Meissner, 1987). Secondly, there appears to be little in the way of a topographic edifice within the Urals to require such a deep crustal root. And finally, the development of the Urals as a late Paleozoic orogen leads to the question of how such a crustal root could have been preserved over geologic time. Preliminary analysis of topographic profiles through the southern Urals, based on the etopo 5 dataset, suggest that the modern topography is not in concert with a significant crustal root. Assuming average crustal (2.5 g cm^{-3}) and mantle (3.2 g cm^{-3}) densities, and Airy compensation, the topographic edifice of the Urals would allow for a

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maximum crustal root (in excess of the regional crustal thickness) of about 4 km. Assigning an effective elastic thickness to the East European plate to support the Urals only reduces the expected magnitude of the root, and in the extreme case of an effective elastic thickness of 50 km, predicts a root of only ~1.5 km. Not considered in this preliminary treatment is the existence of possible subsurface loads.

Since 1983, about 20 seismic reflection profiles have been recorded over the Urals in digital format. Prior to this, 28 profiles had been recorded in analog format. Most of the data are 2-fold down to about 6 seconds TWT, however, some profiles having higher fold or longer recording times are available in digital format (see Table in Appendix A). In addition, a number of shorter test profiles have been shot in the Urals. The reflection data indicate the Urals to contain highly reflective crust with steeply dipping structures, but there are a number of problems associated with the interpretation of these data. These include (i) 3-D effects with reflections from out the plane of the profile interfering with in plane events, (ii) numerous sources attributed to the reflectivity; including shear zones, zones of stress concentration, lithological contacts and metamorphic zones, (iii) complex near surface conditions and (iv) high velocity rocks at the surface. In spite of these problems, distinctive features, such as fold belts and shear zones in the upper crust are observed on the reflection data (Fig. 12). Figure 13 shows a recently collected and processed CDP reflection profile from the western slope of the Southern Urals. Although considerable reflection profiling has been carried out by Russian institutions, there does not exist any deep seismic reflection profiles comparable to data collected in the west by groups such as COCORP, DEKORP or ECORS.

Existing seismic recordings made by geophysicists at Bazhenov in the vicinity of the Ural deep borehole, which reaches to 4.3 km, offer a special opportunity to identify the origin of at least shallow basement reflections. Assessing these recordings and methods of correlation to the borehole with colleagues from the N.I.S. would add considerably to the pool of seismic "calibrations" from deep boreholes such as the SG-3 in the Kola peninsula, the KTB in Germany and Siljan in Sweden. Line drawings from Ural reflection data (e.g. Fig.11) clearly show a number of deeper reflections projecting to surface outcrops. Thus another important approach to gleaning of new information on the origin of deeper reflectivity would simply be to evaluate the extrapolation of particular reflections to the surface. Detailed interpretation of the seismic data, working with geologists familiar with outcropping lithologies as well as the immense library of shallow drill cores, would further contribute to correlating reflectivity to lithology. The gross distribution of crustal reflectivity, and its relation to Uralian terrane boundaries, could provide important clues to origins and ages of reflectivity which have remained beyond the reach of drilling or outcrop. For example, the much debated layered lower crust that is so prominent beneath much of western Europe and the easternmost Appalachians has been interpreted by some to be the result of post-orogenic collapse, either in terms of shear fabrics or related mafic intrusions. Given the apparent lack of such collapse in the Urals (assuming for the moment that the West Siberian basin is unrelated), the presence or absence of well- developed lower crustal layering could throw support either for or against an extensional origin. Whether such layering is continuous beneath the Urals, or is truncated by a particular terrane boundary, would further constrain the age and mechanism of origin. And the relationship, if any, between such layering and the Uralian crustal root would be a novel test of origin, in that shear models for developing such layering are usually associated with flattening of the Moho. Of course, such evaluations of these hypotheses must await the collection of a comparable deep reflection profile across the Urals.

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Gravity Anomalies

Gravity data covering the whole former Soviet Union have been released in digital format recently with respect to Free-Air and Bouguer Anomalies averaged over 20x20 km and 10 x 10 km grids. Figure 14 shows the Free-Air gravity anomalies of northern Eurasia (Kogan and McNutt, 1993). The Urals are characterized by a pronounced linear positive feature lying between the generally positive values of East Europe and the negative values of western and southern Siberia (including Tien Shan- and Himalaya orogens). Point data may be available, subject to an agreement with ROSCOMNEDRA: these are much more closely spaced than the generalized grids discussed above and should provide valuable detailed structural information.

The Bouguer anomaly of the Urals is dominated by a long-wavelength gravity minimum (approx. -50 mgal over 400 km) and a short-wavelength gravity high (approx. + 50 mgal over 100 km) along the Main Uralian Fault and the root of the orogen (see gravity map in Appendix B). Residual gravity anomalies after subtraction of the effect of the sediments and the Moho topography reveal the existence of yet unknown masses in the crust and in the upper mantle (Artemjev et al., 1993).

Fig. 8: Location map of existing long-range deep-refraction profiles (deep seismic sounding DSS) in and around the Urals. The QUARZ profil (by GEON, Moscow) contains superdeep soundings using nuclear explosions. The other profiles were conducted by UralGeolCom (BGE Sheelite). The East European - Siberian transect GRANIT contains the special 3-dimensional anisotropy experiment ASTRA (by University of Karlsruhe and BGE Sheelite, 1991). Thick black points mark locations of the Superdeep Drilling Program. SG-4 (Uralskaja) is located at the intersection of the profile GRANIT with the Ural Mountains.

Fig. 9: Map of crustal thickness (after Rybalka et al., 1992, see Appendix B).

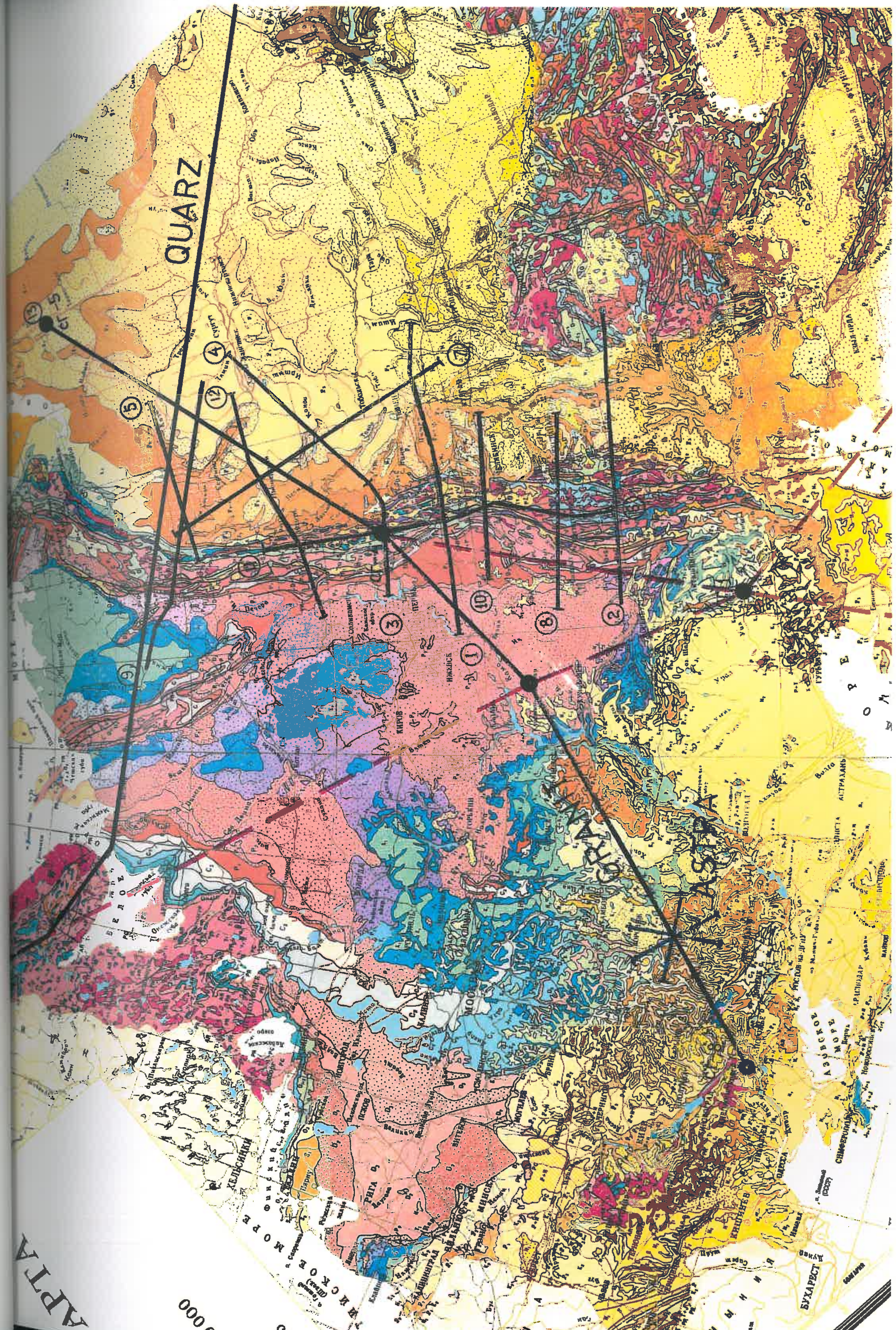
Fig. 10: Interpreted DSS profiles (analog recording on magnetic tapeacross the middle and southern Urals (reportet by Kashubin et al. 1992, Appendix A). Shown are discontinuities (sub-horizontal, with numbers for seismic velocities in km/s) and fault zones or boundaries of crustal megablocks (sub-vertical).

Fig. 11: DSS profile across the middle Urals collected and interpreted by BGE, Sheelite. Line drawings represent wide-angle reflections seen in single-fold data.

Fig. 12: Example of a low-fold reflection profile of the upper crust and its interpretation by BGE, Sheelite. On top: anomalies of the vertical intensity of the magnetic field, gravity field, superficial seismic velocities.

Fig. 13: Example of a CDP profile collected at the western slope of the Southern Urals in hydrocarbon exploration (for details Kashubin et al., 1992, Appendix A) and its interpretation.

Fig. 14: Free-Air gravity anomaly of northern Eurasia (Kogan and McNutt, 1993).



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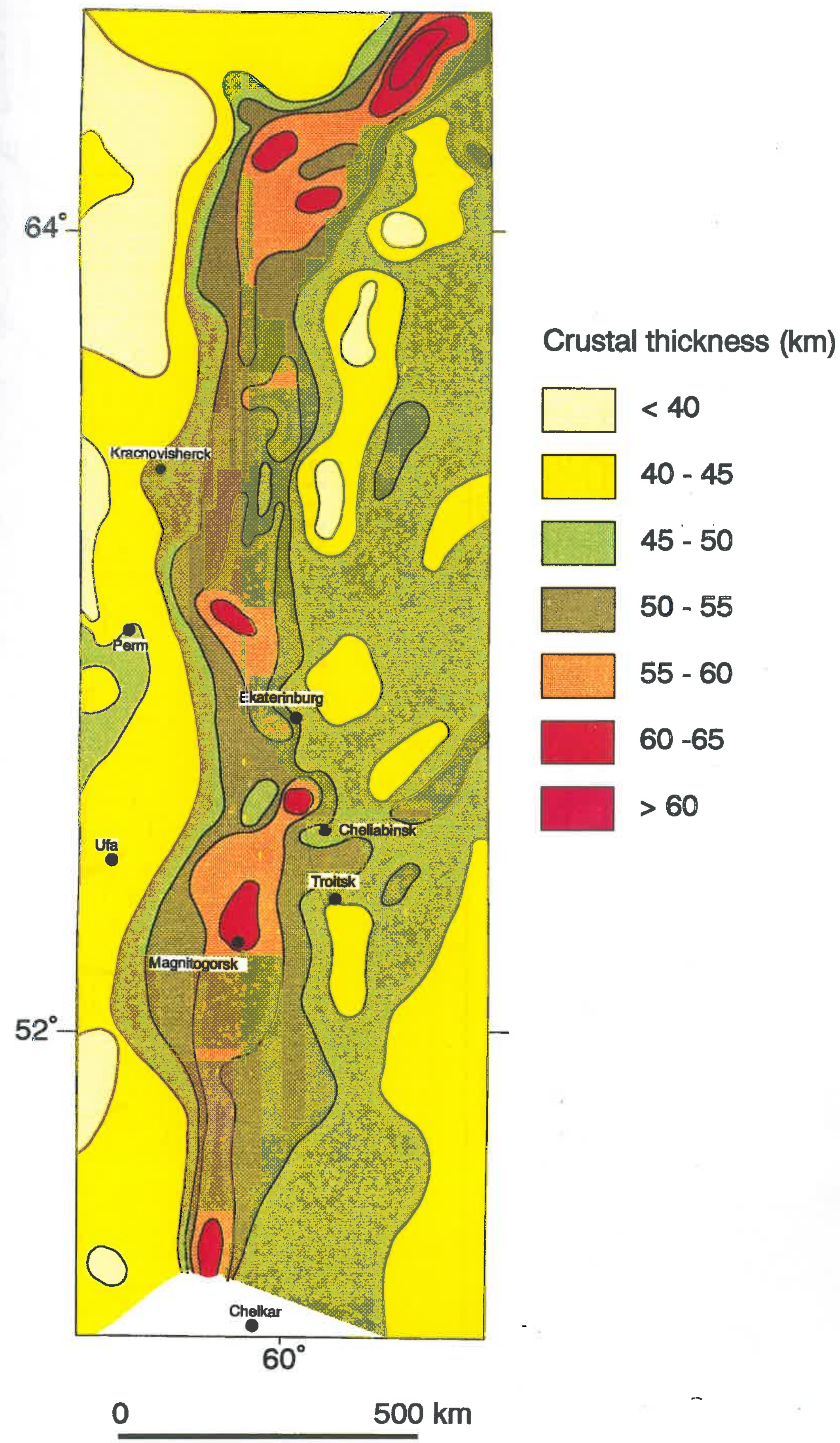

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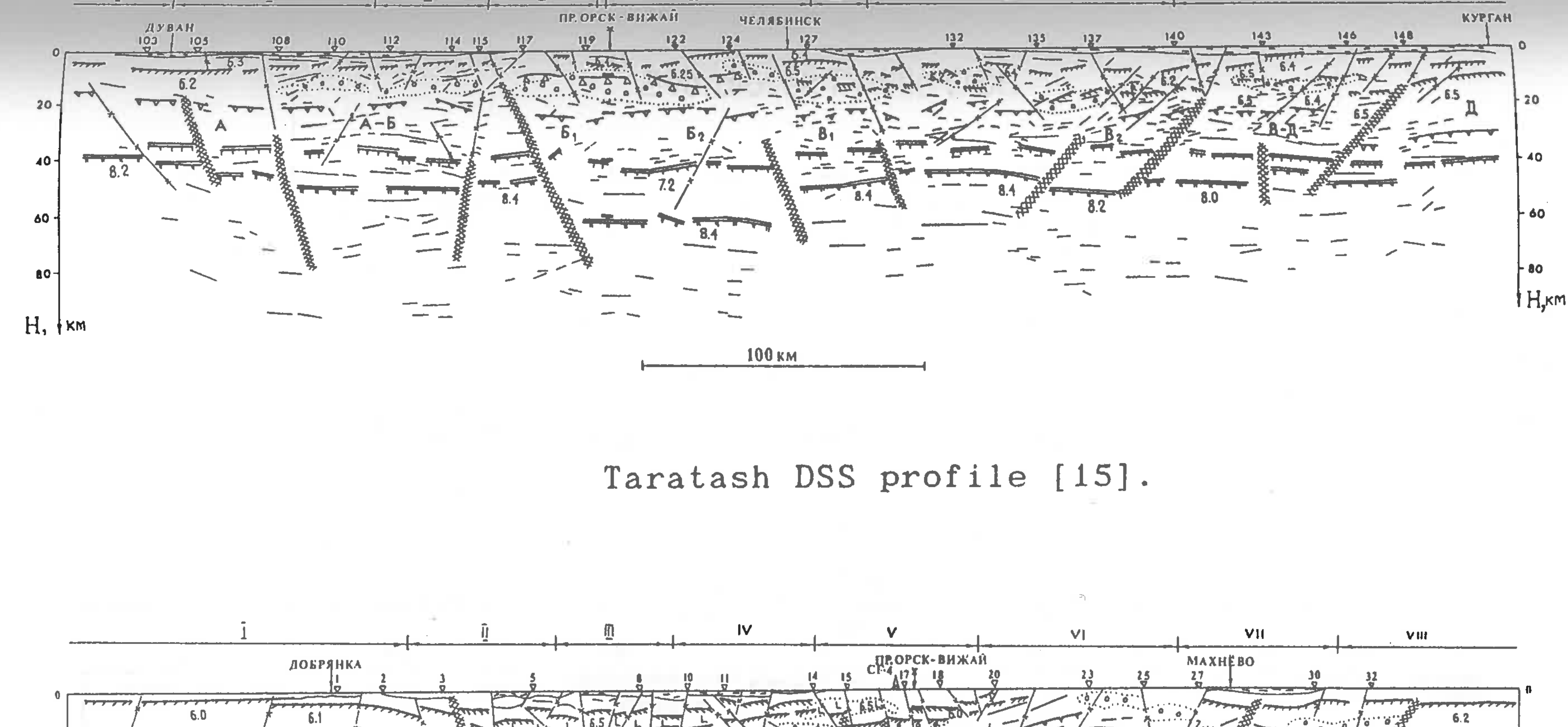
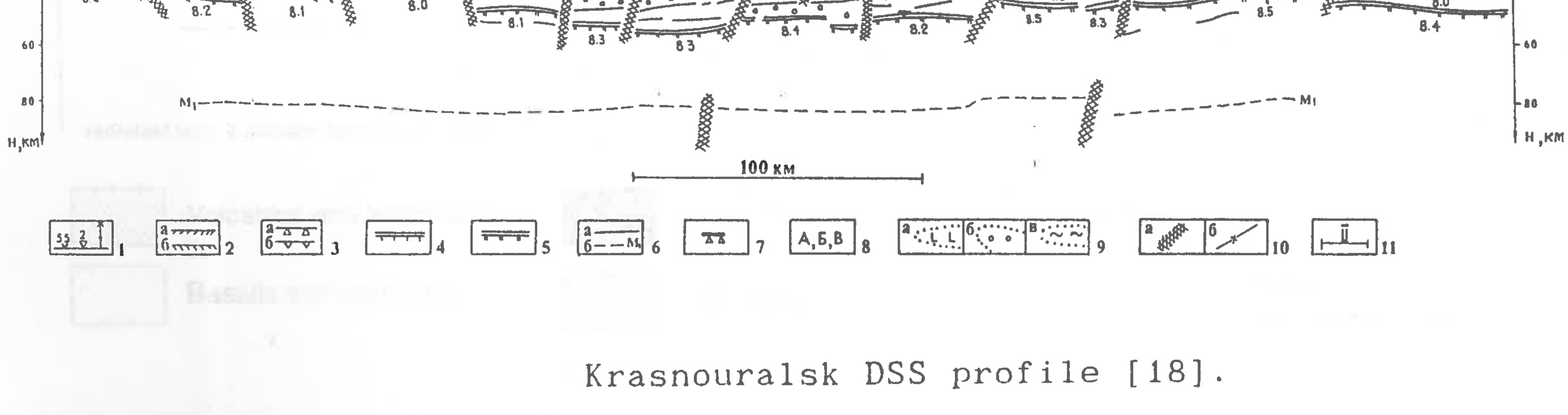


Taratash DSS profile [15].



Krasnouralsk DSS profile [18].

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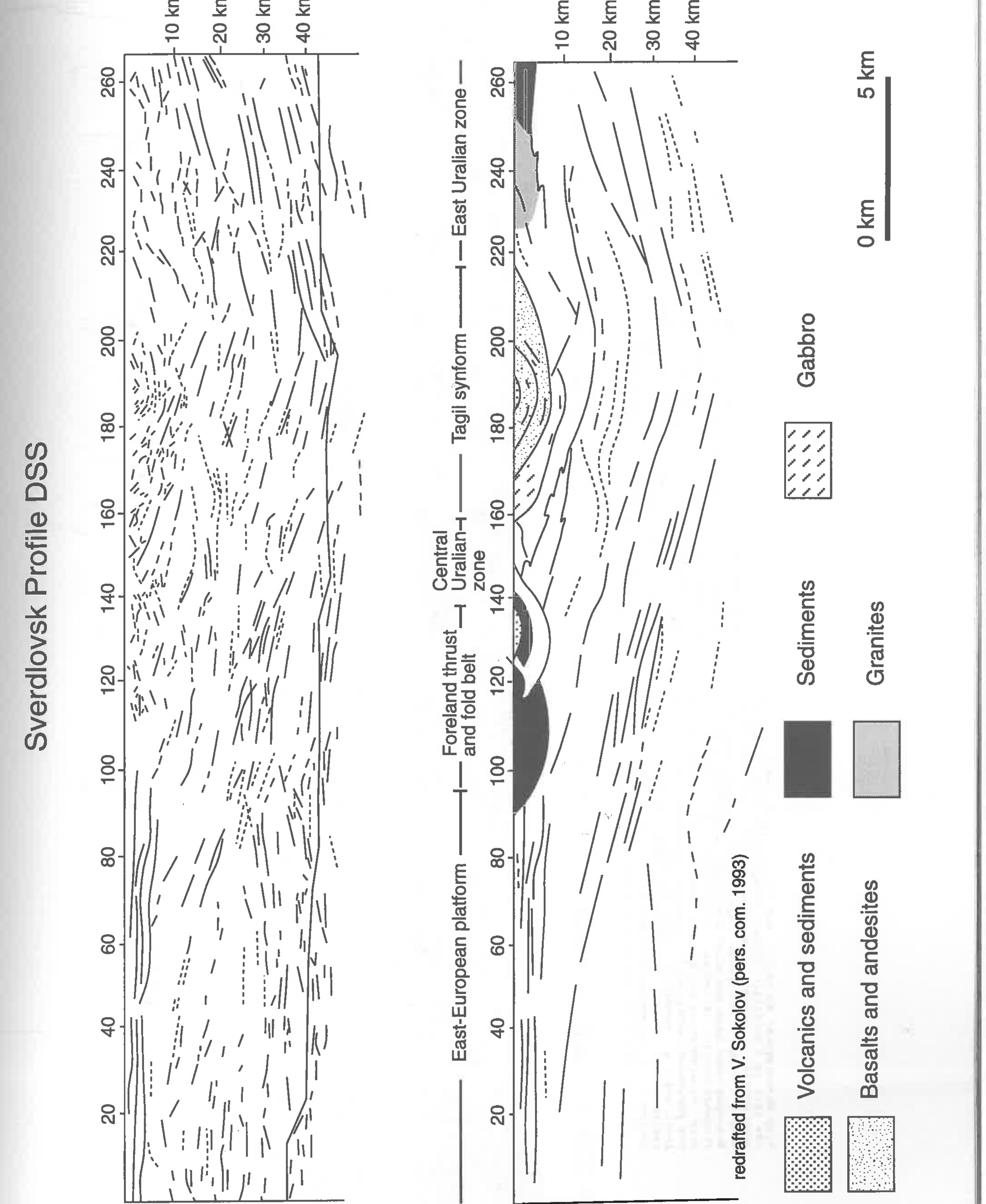

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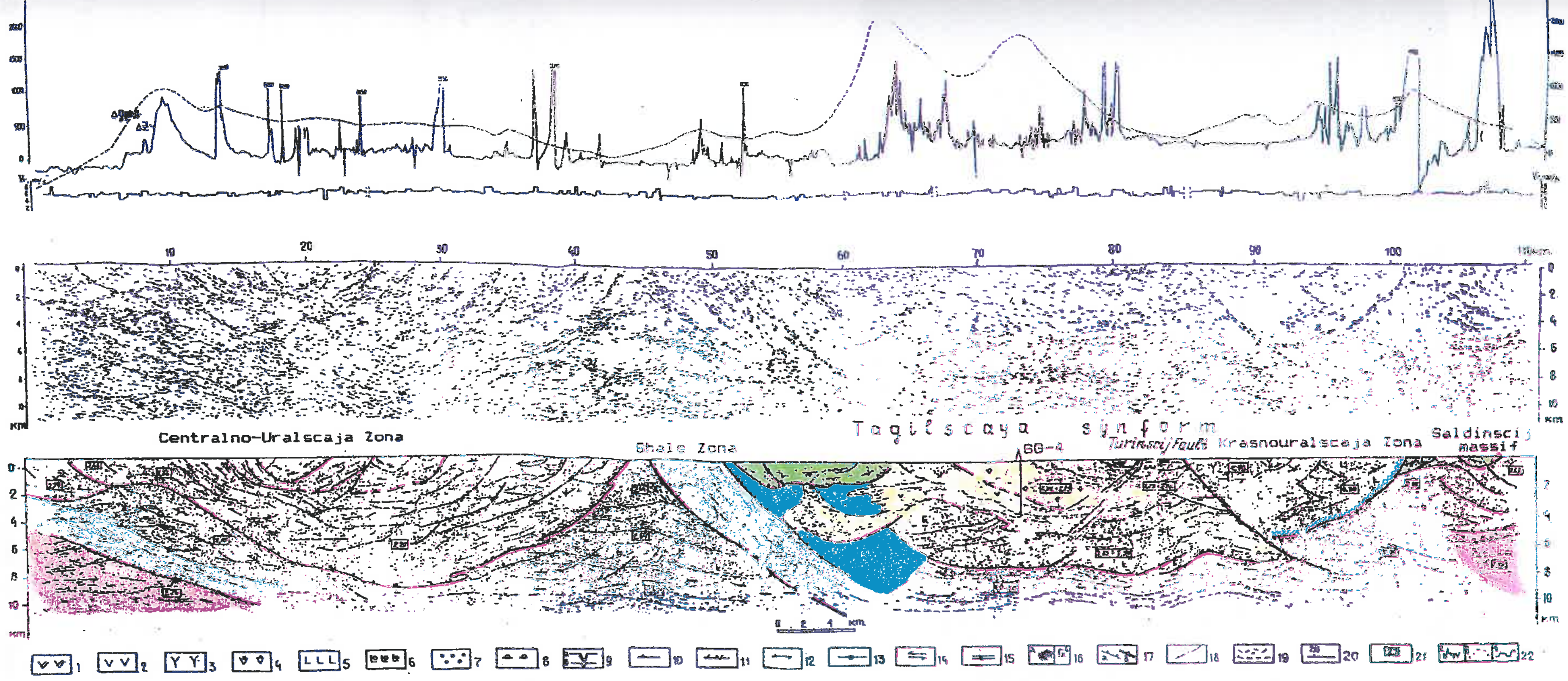

I – transitional and flyschoid series (acidic volcanite, daeite); 2 – volcanogenis-clastical coorse fragmental andesite-basalt series; 3 – andesite-basalt porphyrite and their tuff; 4 – andesite- basalt and basalt tuff, porphyrite and tuffstone interlfyers, limstone plates; 5 – volgcanites with playiogranite and diorite bodies; 6 – trachyte and trachyte-dacite volcanite (undivided); 7 – sandstones, gravelstoness conglomerates, quartzitic sandstones, limestones; 8 – sands, sandstones, aleurolites, shale rocks; 9 – amphibolize diabases, greenstohe slates (a), amphibolites (b); 10 – sericitic schist, guartzo-miga-chlorite slates with gravelstore, sandstone and marlle interlayers, quartz schist with chlorite, sericite and coal matter; 11 – apovolcanic schists, meta-basalt; 12 – dynamoschists; 13 – coal, coal-chlorite states; 14 – biotite, biotite-garnet schists, amphibole-biotite amphibolite, dynamoschists with gabbro bodies, quartzites; 15 – crystalline basement of platform; 16 – serpentinuous ultramafite; 17 – thrusts (a), regional thrusts (b); 18 – disjunctive breaks; 19 – reflution elements and conditional seismic boundarios; 20 – line of profilewith shotpoints; 21 – density of rocks (g/cm3); 22 – diagrams Z(a), g (conditional level) (b), boundary velocity.

Sokolov 1992 Profil (3)

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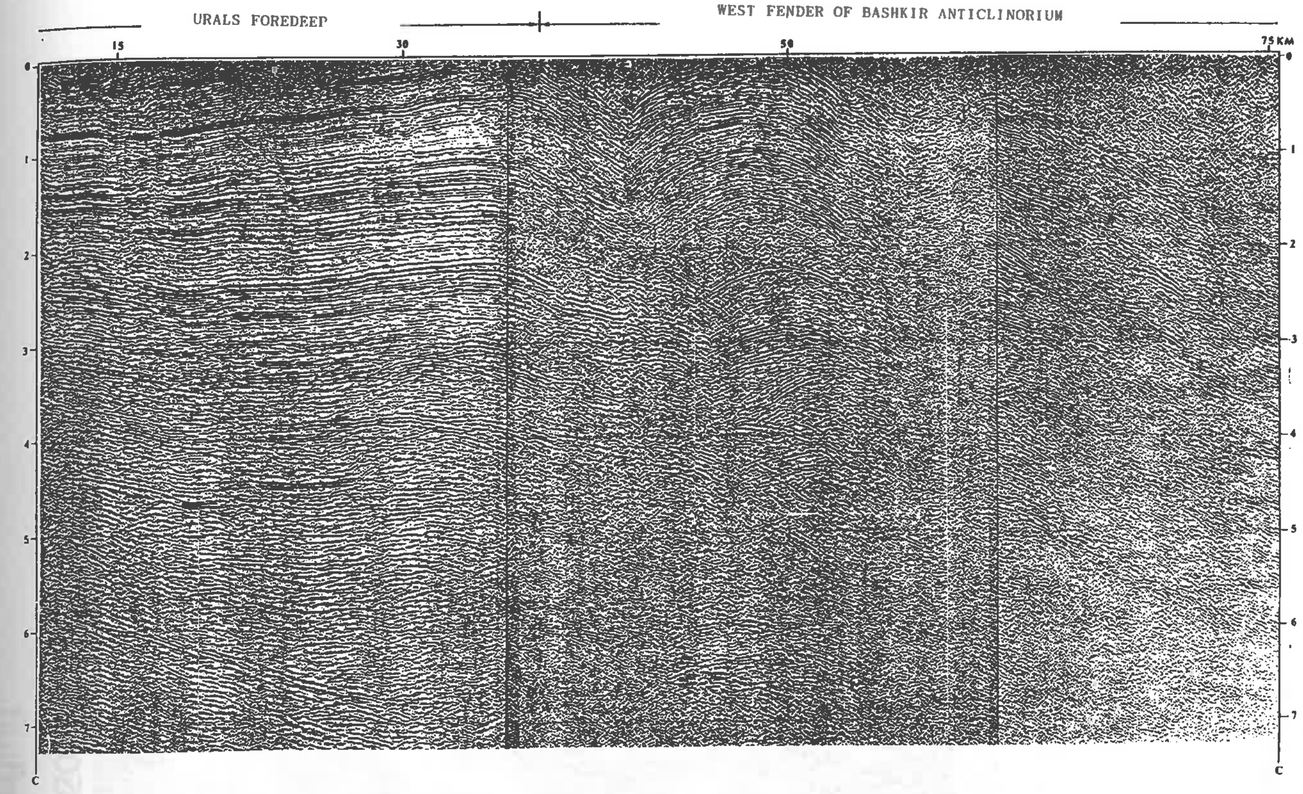

Fig.10 SEISMIC SECTION FRAGMENT OF THE 06 CDP PROFILE
WEST SLOPE OF THE SOUTH URALS [27].

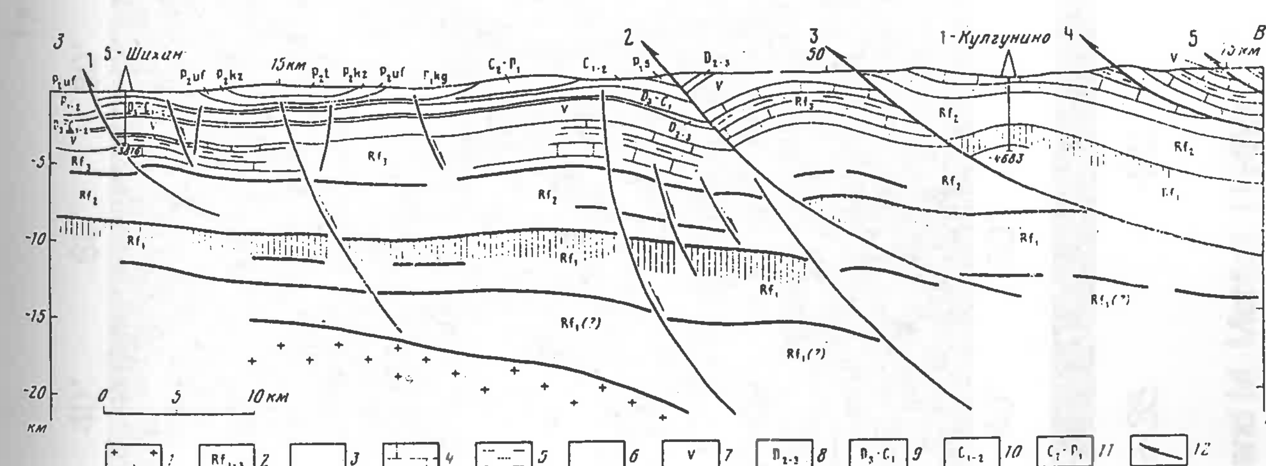

Fig. 11.

Geological cross section on the base of the 06 CDP profile data [27].

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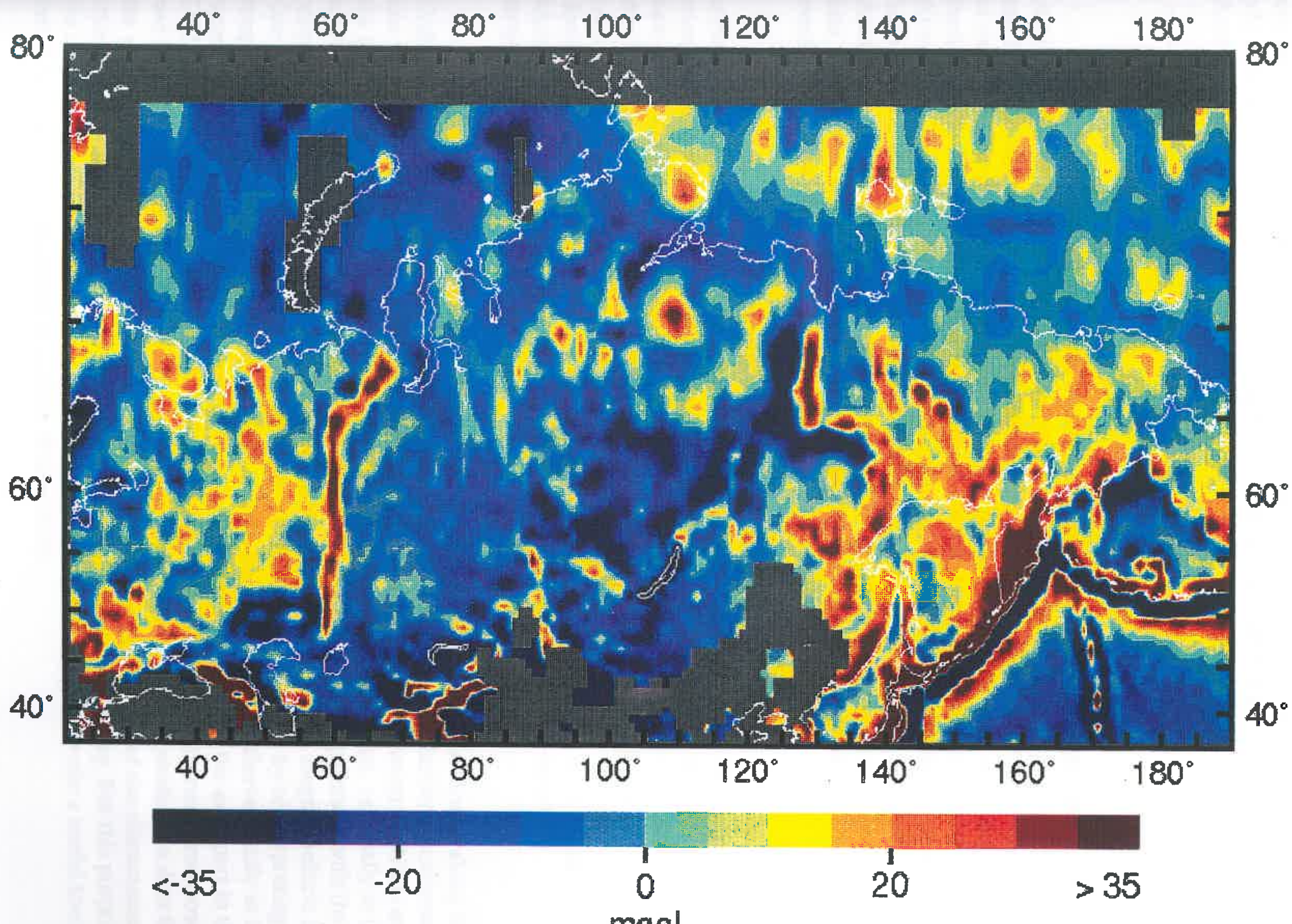
From: Mikhail Kogan

Free-air Gravity Anomaly over Northern Eurasia

1x1 degree averaging



M. Kogan and M. McNutt (1992)
Data sources over land: Topographic Service of Armed Forces of Russia
over ocean: Geosat altimetry processed by W. Haxby (L-DGO, Palisades, USA)

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Magnetic Anomalies

The total intensity of the magnetic field has been measured by airborne surveys at altitudes of 150 m, 2000 m and 4000 m. These data reveal long-wavelength (approx. 500 nT) anomalies caused by deep reaching bodies as well as numerous short-wavelength (1000-2000 nT) anomalies, which have been the target for mineral exploration (see magnetic map in Appendix B).

Heat Flow

Heat flow has been measured in about 150 locations in the Urals and the preliminary results are shown in Appendix B,C. The average heat flow in the Ural foldbelt is 29 ±6 mW/m^2 and the Urals represent a long narrow zone of low to very low heat flow stretching along most of the axis of the mountain belt. In the north, this region of low heat flow separates the Timan-Pechora basin from the West Siberian platform, both units being typical with heat flow at 50-60 mW/m^2. The lowest heat flow values are observed in the Southern Urals (25 mW/m^2); further to the south heat flow increases again to 60 mW/m^2 towards the Cis-Caspian depression. To the southeast the continuation of the heat flow field is not clear, but probably heat flow is low. The Urals foredeep is also characterized by low, but somewhat higher average heat flow observations of 36±8 mW/m^2.

The Urals present an important target area for general heat flow studies in a global context. Such a zone of low heat flow is an extraordinary feature and must correspond to a crustal section which is extremely depleted in radioactive elements, but in addition exhibits low heat flow from the sub-crustal lithosphere. Crustal temperatures have been calculated to a depth of 70 km along the 520 km long Taratashskiy refraction profile, crossing the Ural mountains along latitude 56°N. The steady-state model was solved numerically with the vertical distribution of heat production derived from the seismic velocities. It was shown that, at the Moho boundary, the mantle heat flow varied between 10-20 mW/m^2 and the Moho temperature was 350-500°C.

Simple 3-D geothermal modeling of a standard crustal structure performed along the Urals and in the adjacent parts of the East European and West Siberian platforms confirmed low lithospheric temperatures with less differences in deep conditions between the Urals and the East European platform, but a relatively sharp contrast towards the east, especially in the north. Low lithospheric temperatures below the Urals are thus in good agreement with the supposed absence of the asthenosphere based on the interpretation of the magnetotelluric data. One of the objectives within EUROPROBE is to verify the low heat flow by reinterpreting temperature logs from several boreholes and to focus on the detailed geothermal study in the superdeep Uralskaya borehole. If regional heat flow below 30 mW/m^2 in the axial part in the Urals is confirmed, the explanation of such an anomaly has to be sought in crustal composition and in depletion processes. The thorough compilation of radiogenic heat production data from the existing boreholes plus the assessment of the typical heat production of the characteristic crustal rock types to construct the petrophysical crustal model is necessary. For this purpose the combined heat flow and near surface heat production studies may provide a useful tool for better downward extrapolation of surface observations.

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Electromagnetic Studies

Magnetotelluric measurements have shown that a pronounced conductivity anisotropy exists beneatch the axis of the Urals which is parallelled by two narrow high-conductivity zones in the mid-crust (Dijkonova et al., 1992, pers. comm.). Additional electromagnetic studies using natural and controlled sources along the projected seismic reflection transect are necessary to enable integrated interpretations.

Stress Field

The World Stress Map project (Zoback, 1992) has revealed that the stress orientations and stress regimes are consistent both regionally and with depth, and permit the definition of stress domains (or first-order stress fields) with characteristic stress fields of dimensions ranging from 20 to 200 times the thickness of the upper brittle lithosphere (ca. 20 to 25 km). Intraplate or midplate regions are, with some exceptions, characterised by strike slip or thrust fault stress regimes in which the maximum principal stress is horizontal. Thus, the interiors of lithospheric plates are generally under compression. The directions of theses domains often coincide with the direction of plate motion and the tectonic stresses are ascribed to result from lateral plate boundary forces, such as ridge push and plate collision. The investigations of the stress field in Western Europe have shown, that the western European stress field is characterized by a dominant NW-SE orientation of the maximum horizontal stress S_H and variations of the tectonic regime from dominantly strike slip to normal faulting. This is equivalent to alternating stress conditions characterized by either $S_1=S_H$ or $S_1=S_v$. Only S_3 constantly is equivalent to S_h and trending in a NE-SW direction.

The contemporary state of stress (orientations and magnitudes) of the East European craton and the Urals is unknown and should be defined as one of the major targets of geoscience investigations. The gap in the contemporary stress data arises since there is a lack of larger seismic events and only recently experiments focussed on the relation between seismic anisotropy and the stress field. Concerning the paleo-stresses it can be expected, that the N-S trend fo the Ural Mountains indicates a E-W compression during the orogeny. Similarly, the NNW trend of the Tornquist Teisseyre with its thickened crust and lithosphere may lead to the conclusion, that during the docking of western Europe to the East European Platform a paleo-stress perpendicular to the trend of the TTZ existed.

The knowledge of the contemporary stress orientations mainly comes from boundary areas of the East European Platform. To the north, the focal mechanisms and in-situ measurements in southern Finland indicate a NW-SE stress orientation as it is dominant to the west of the Tornquist -Teisseyre-Zone. In the south, there is a change of stress orientations from N-S extension in western Turkey to a roughly N-S compression in Eastern Turkey, which is interpreted to reflect the forces that are responsible for the escape of the Anatolian plate to the west. Focal mechanism data indicate that the N-S compression persists to the area bounded by the Black Sea and the Caspian Sea. In the southern Urals a small number of shallow overcoring measurements exist, which show an E-W trend of stress orientation. This requires a rotation of 90° between the Caspian Sea and the Ural Mountains. Recent borehole breakout investigations in the well Vorotilov (central East European Platform) and Uralskaja (Urals) have shown, that the orientation of the maximum horizontal stress is WNW to NW and thus very similar to the NW-SE orientation of western Europe. However, it is still unknown, whether S_H equals S_1 or S_2.

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In contrast to the Western European stress field with S_1 alternating from vertical to horizontal, the stress domain in the eastern North American craton is characterized by thrust faulting. The question now is : how does the East European Platform react to the stress field? Does the thinner lithosphere together with the higher geotherms in western Europe lead to a stronger stress concentration which is less affected by local sources of tectonic stress in comparison to the cold and thick lithosphere of Eastern Europe? What is the role of the Urals? Is their influence large enough to modify stress magnitudes or directions or is there evidence, that the stress field is not affected by the Ural Mountains?

Seismicity

Major historical earthquakes are reported from the Middle Urals. Figure 16 (Kashubin and Druzhinin, 1993, pers. comm.) shows earthquake locations with magnitudes between 4 and 7. Studies of the seismic anisotropy along a N-S refraction profile revealed correlations with the seismic activity, which might indicate that the anisotropy is stress-induced (Kashubin, 1993, pers. comm.). It is still unknown whether the distribution of earthquakes is biased towards the middle region due to denser population or due to the location of existing instruments. A permanent seismograph network for monitoring the seismic activity allover the Urals is being planned in cooperation with the IRIS program. This would allow to locate the earthquakes more precisely and to determin fault plane solutions.

Recent Tectonics

The present relief of the Urals (approx. 2000 m maximum in the South and in the North, nearly no relief in the middle Urals) is the result of recent vertical movements during the last 10 Mill. years. Vertical movements of the order of 2 mm / year were reported from Russian geodetic measurements. Modern GPS measurements to monitor vertical and horizontal movements have been initiated by the GFZ Potsdam.

Superdeep Drilling

The borehole SG-4 of the Russian Superdeep Drilling Program is located in the Tagil-Magnitogorsk Zone east of the Main Uralian Fault approximately 150 km north of Ekaterinburg. One of its primary aims is to drill through the Main Uralian Fault at greater depth and to analyse it. This situation allows for the rare opportunity to calibrate deep reflections in the context of a deep-reaching tectonic fault zone.

Drilling operations have reached 4700 m during summer 93 and are still in progress. A bitsize of 215 mm is used during drilling, afterwards the hole is rimed to 394 mm. A casing has been implemented to 3958 m. The core recovery is at the average of 64 % . An example of preliminary logging results is shown in Fig. 17. Vertical seismic data of good quality are still lacking. A new field campaign including vertical seismic profiles is being planned by the Universities of Glasgow, Karlsruhe and Uppsala in collaboration with the ROSCOMNEDRA institutions. Borehole televiewer data for stress field studies have been collected by GFZ Potsdam and the University of Karlsruhe in summer 93.

Mineral Resources and Economical Significance

The Ural Mountains are well known for their rich potential of mineral resources (see map of mineral resources in Appendix B). The mineralizations and ore deposits are genetically strongly connected with the zonation of the Urals (based on rock formations) and with the facies distribution of sedimentary, volcanic and intrusive rock bodies and their later weathering. The metallogenetic stages from Archaean time onwards are related to different types of mineralization.

The resources in the Eastern Urals are expecially Carboniferous coal measures and sedimentary iron ores. The Granite Belt contains different types of (1) gold (with tungsten) deposits, (2) copper ores and (3) sulphidic ores. (4) Pegmatites and alkali-rich rocks are sources for precious and semiprecious minerals. The island arc and the back arc area of the Magnitogorsk Zone is spezialized in (1) magnetic (skarns) and chalcopyrite, (2) copper deposits, (3) sulphidic ores, (4) manganese, partly with jasper beds and (5) malachite. Eurasia`s richest platinum belt (with Ni and Cr) is related to mafic and ultramafic intrusive bodies (mostly dunite), which are not interpreted as a part of an ophiolitic suite.

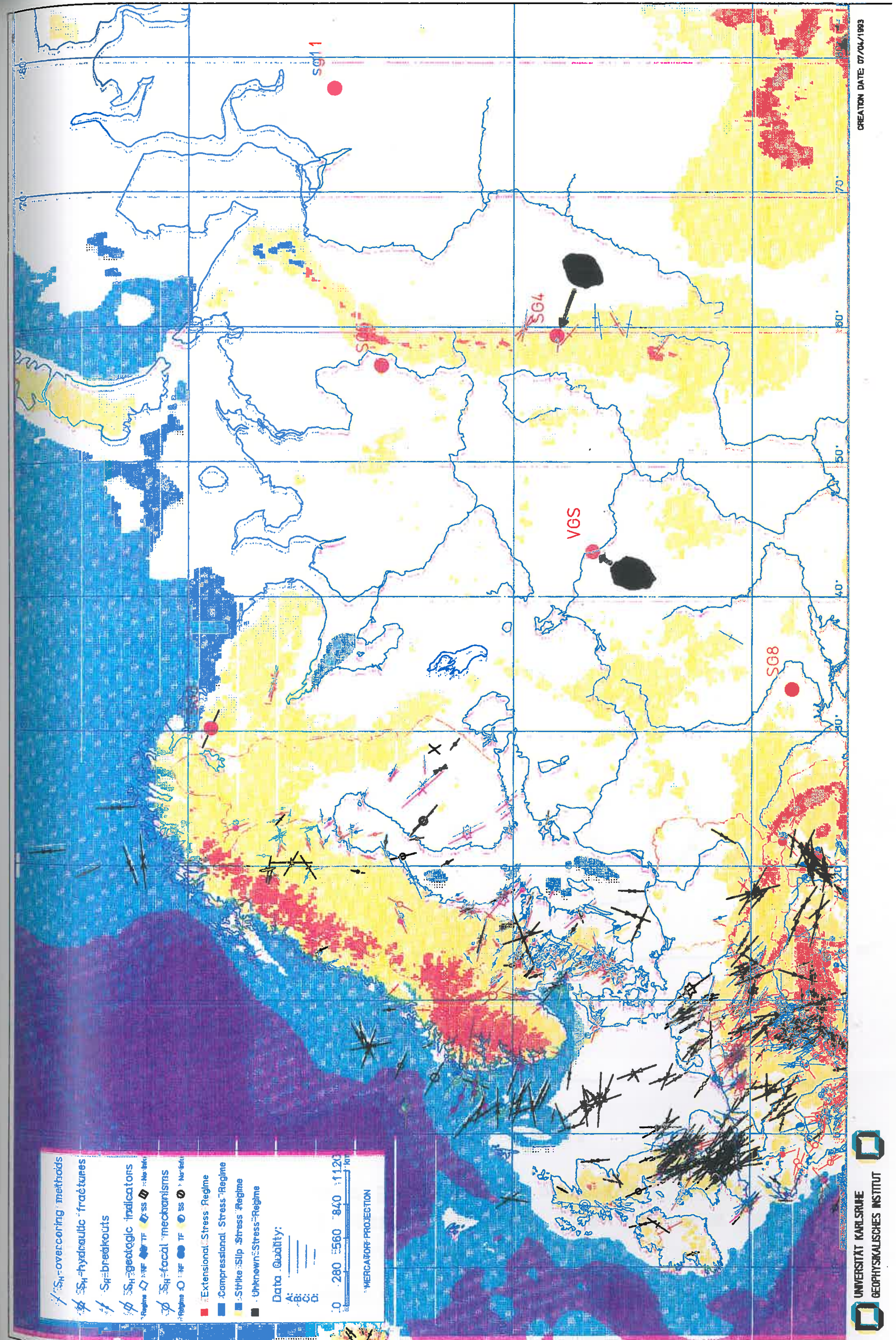
The Archaean units in the Western Urals contain iron quartzite formations, the Riphaean units include siderite-magnesite ores, baryte and stratiform polymetallic ores. The Paleozoic series on the western slope are rich in oil and gas, bauxite, copper sandstone and potassium salinar.

Basins adjacent to the Urals (West-Siberian, Timan-Pechora, West-Uralian foredeep and Caspian) are amont the world-richest hydrocarbon bearing areas.

Fig. 15: Stress map of Europe emphazising new data in Eastern Europe and the Urals obtained at the boreholes Vorotilov and SG-4 (University of Karlsruhe).

Fig. 16: Map of historical earthquake distribution (since 1750) in the Urals. Magnitudes are size-coded between 4 and 7.

Fig. 17: Recently collected logging from the borehole SG-4



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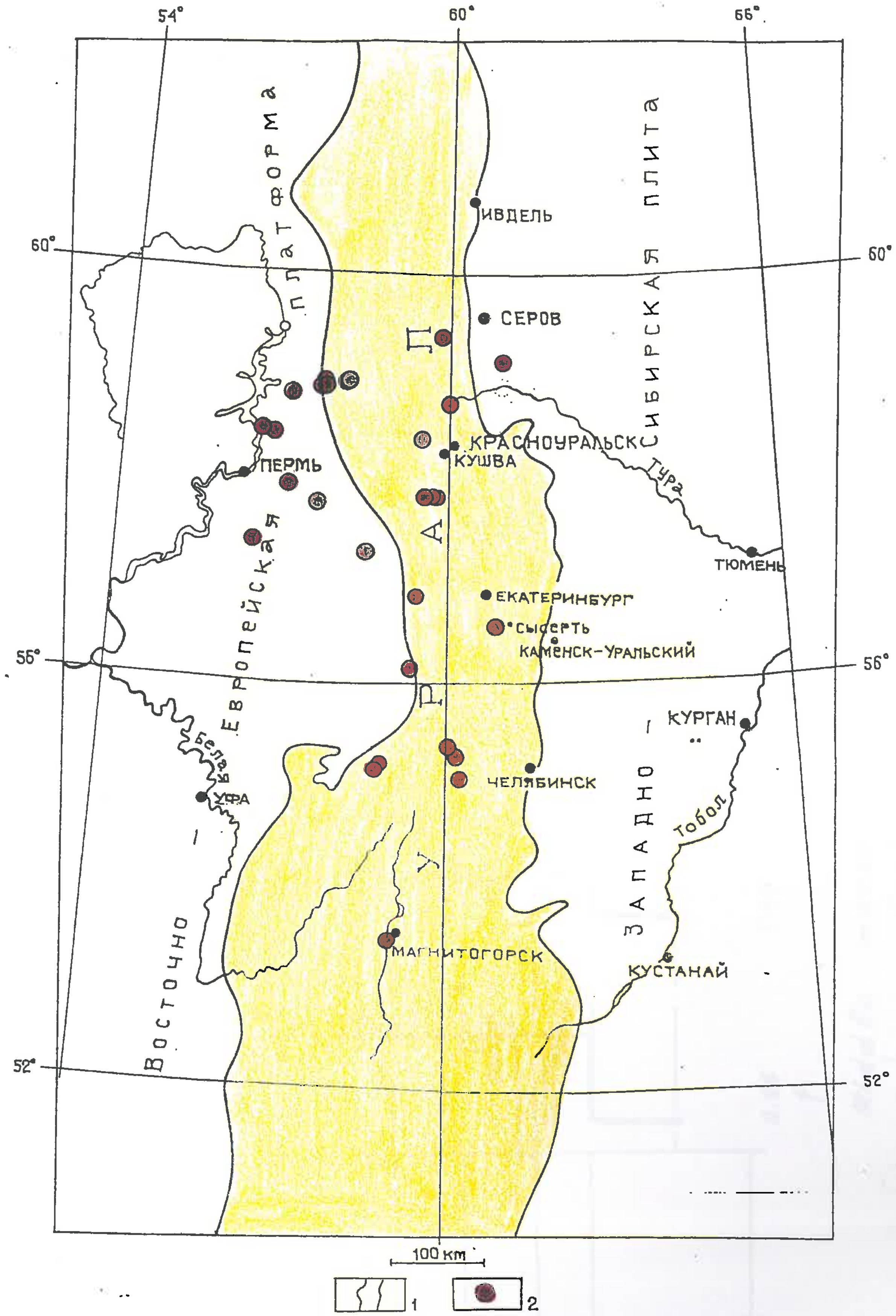

Рис. I. Схема расположения эпицентров землетрясений с бальностью более 4 в Уральском регионе (по данным [8,10,11])

I - границы открытого Урала; 2 - эпицентры землетрясений

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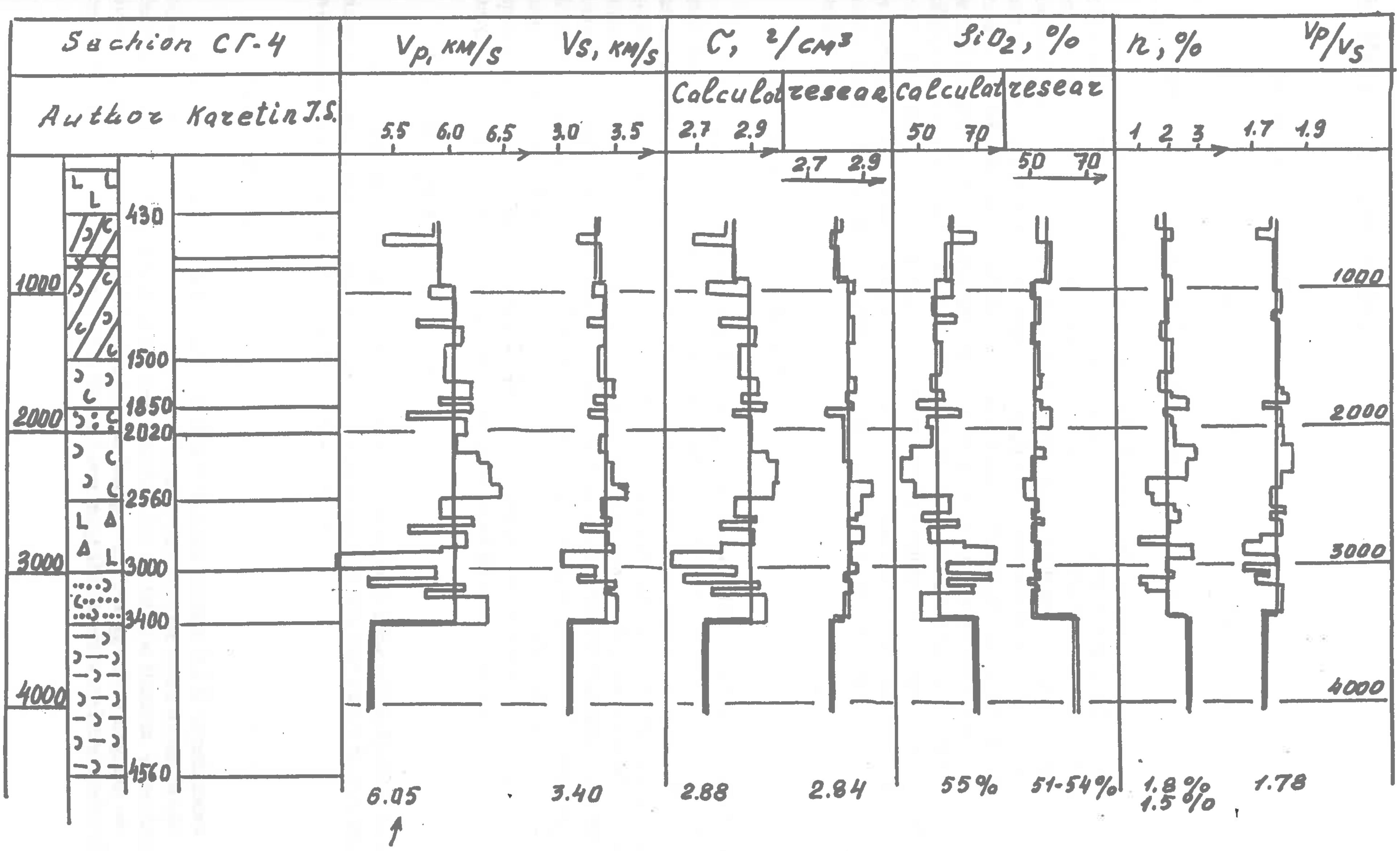
Gealogy - Geophisical charactaristik of the СГ-4



Middle means up to the 3400 m

V. Amzhinin Ecaterinburg tel. 34-32 28-56-96, fax 28-57-.

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IV Recent Achievements

Europrobe Workshops

Three EUROPROBE workshops were devoted to the Uralides-Variscides comparison:

Sheelite/Zarechny, Russia, 6-14th May, 1992

EUROPROBES first ESF workshop as held in the Urals. It was organized in collaboration with the Bazhenov Geophysical Expedition in Sheelite, preceeded by a 200 km long excursion from Europe into Asia across the central Urals. The lower thrust sheets of the European margin were traversed, through the Main Uralian Fault into the ophiolites of the main allochthon and in the east in hinterland complexes, extensively intruded by Paleozoic granites. The Middle Urals is not the best exposed part of the orogen, but a good feeling for the regional geology, the existing data base and the exciting possibilities for future collaboration was obtained. Four days of lectures, mainly by researchers from the N.I.S., provided the thirty outsiders with a good overview of the Uralides. Agreements were signed for exchange of data: science plans for the Uralides were outlined. It was agreed that these should include a deep reflection profile across the orogen, either through the middle or southern Urals.

Perlora, Spain, 6-15th March 1993

The programme in Perlora (near Oviedo) focused on two objectives: firstly, to define in detail the science plans for the Uralides and, secondly, to examine the Variscide geology of a transect along the north coast of Spain, based on new seismic reflection profiling and other geophysical data. The meeting was attended by 60 geoscientists from 13 countries, including a particularly strong contingent (14) from the Urals. Much of the workshop was devoted to discussion of Uralide research objectives, particularly the merits of alternative transects in the Middle and Southern Urals for the CDP profile. In addition to the results from the on-going work reported above. First data of the French-Russian UWARS wide-angle reflection experiment, as well as first results from reprossing of Russian reflection data at Uppsala University demonstrating high crustal reflectivity down to 30 km were presented.

Evora, Portugal, 6-10 March 1994

The programme in Evora focussed on discussion of recently achieved results from new seismic experiments and from reprocessing of previously existing data (see section below) and on discussion of technical details of the proposed experiment.

Joint Data Base

There have been significant amounts of data exchanged between N.I.S. organizations and western institutions over the last few years. Magnetic data from the entire former Soviet Union at a resolution of 2x2 km grids has been transferred to the BGR in Hanover, some data have also been analyzed by the BGS in the UK. Surface gravity data are still lacking, but we hope to be able to obtain these data in the future. Long range DSS profiles are being analyzed

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in Karlsruhe. Several reflection seismic lines have and are being reprocessed at the Universities of Cornell and Uppsala, results of which are described in the next section.

Russian geologists have been actively supporting field studies in the Urals by scientists from Potsdam, Oviedo, Granada and Cornell. In addition, they have been making available data on geochemical analyses, mineralogy and age dating of rock samples.

French-Russian Teleseismic Wide-Angle Experiment: UWARS 1992

The UWARS experiment (Thouvenot, 1993) was the first cooperative seismic experiment within the Urals (Grenoble, GEON and the BGE) where teleseismics were recorded across the Urals during the summer of 1992. In addition 7 shotpoints were recorded at critical distances to the Moho perpendicular to the profile. These recordings support the interpretation of the previous data of a root below the Urals with a trough in the Moho topography as one crosses from the East European Platform into the Urals, although this Moho depression is less pronounced than in the Southern and Northern Urals. Figs 18 and 19 show a preliminar data presentation by Thouvenot (1993, pers. communication) and a velocity-depth model by Egorkin et al. (1994, pers. communication).

Reprocessing of Seismic Data

A number of Russian seismic data sets are being reprocessed (for location see Fig. 20). A brief summary of this work is given below:

Surface seismic data over the SG-4 borehole

Two Russian data sets over the SG-4 borehole have been reprocessed, one focusing on the upper 15 km (Bliznetsov and Juhlin 1994) and the other on the approximate interval 10-50 km (Juhlin et al. 1993). Both profiles were rather short (about 7 km long), however, they showed the crust to be clearly reflective from the surface down to the expected Moho depth of 50 km (Fig. 21).

R17 Seismic Reflection Profile

The 70 km long R17 profile was shot in 1993 by the BGE as an oil and gas prospecting enterprise in the West Siberian Basin. Data were recorded to 4 s at a shot spacing of 50 m. However, through extra funding from Uppsala University, every 8th shot was recorded to 20 s. The 20 s data were processed in Uppsala and show the crust to be reflective down to at least 13-14 s (~40-45 km) east of the Middle Urals.

Reprocessing of Russian data from the south Urals

Two Russian CDP profiles (both about 80 km long and referred to as R114 and R115) from the southern Urals are being reprocessed at Uppsala University. Very preliminary results from the western half of one of them (Fig. 22) show a significantly different pattern in the reflectivity over the Ordovician-Lower Permian Shelf Complexes than in the Precambrian Basement on the western half of the ESRU1993 profile.

Reprocessing at Cornell University

COCORP members of the Cornell University are currently reprocessing data form the Aramashevskii (3.32), Chernoistochinskii-Alapaevskii (3.34), Sosnovskii (3.48), and the deep refraction records from the GRANIT survey near the SG-4 borehole. To date, results are available from the Aramashevskii line.

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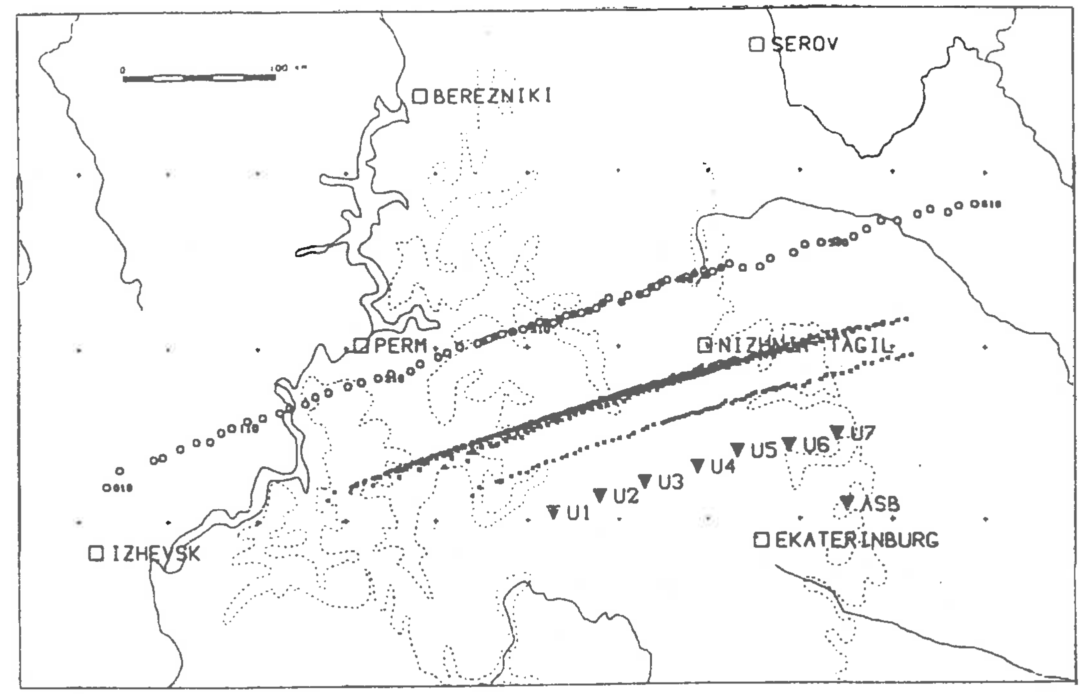
Fig. 18: Top: Location map of the UWARS experiment across the Middle Urals: GEON stations (open circles). BGE stations (solid circles), shotpoints (full triangles), and midpoints (crosses). Bottom: Preliminar West-East cross section for P-waves after Normal-Moveout correction (with average velocity of 6.5 km/s), with Moho (dotted) and lower-crustal reflector (dashed). From F. Thouvenot, EUROPROBE NEWS, 1/1992, 4/1993.

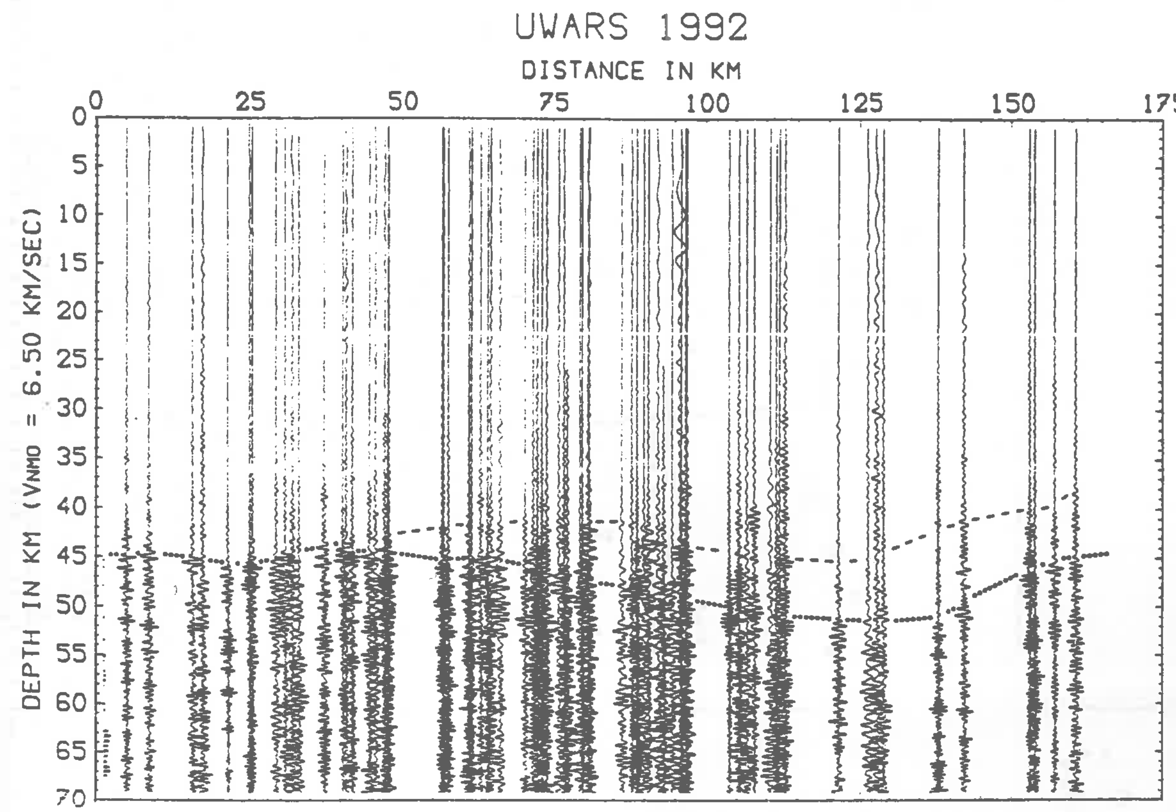
Fig. 19: Velocity-depth model from the UWARS experiment obtained by Egorkin A.V., Rakitov, B.A., Zolotov, E.E. et al., 1994, pers. communication). Numbers in each layer are P-wave velocities (top), S-wave velocities (bottom) and Vp/Vs-ratio.

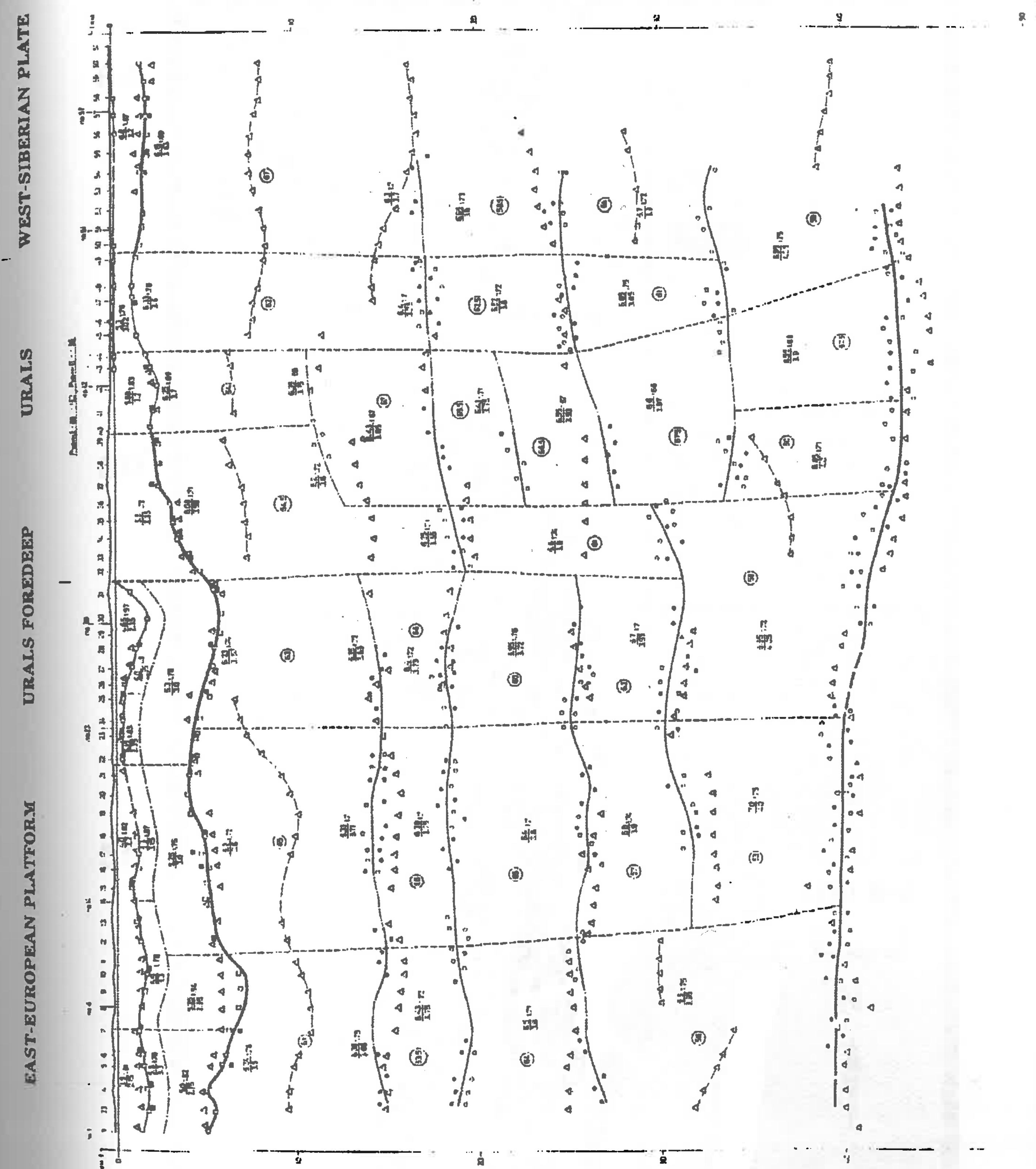
Fig. 20: Location map for reprocessed reflections lines

Fig. 21: Stacked CDP sections, A: True amplitude stack, B: Trace amplitude balancing over a 4 second window, and with a 5 trace coherency filter applied. Vertical to horizontal scale is approximately 1:2. From Juhlin et al., 1993.

Fig. 22: Stacked CDP section from a 80 km long profile from the western part of the Southern Urals (C. Juhlin, pers. comm.)







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Egorkin A.V., Rakitov B.A., Zolotov E.E. et al.
1994

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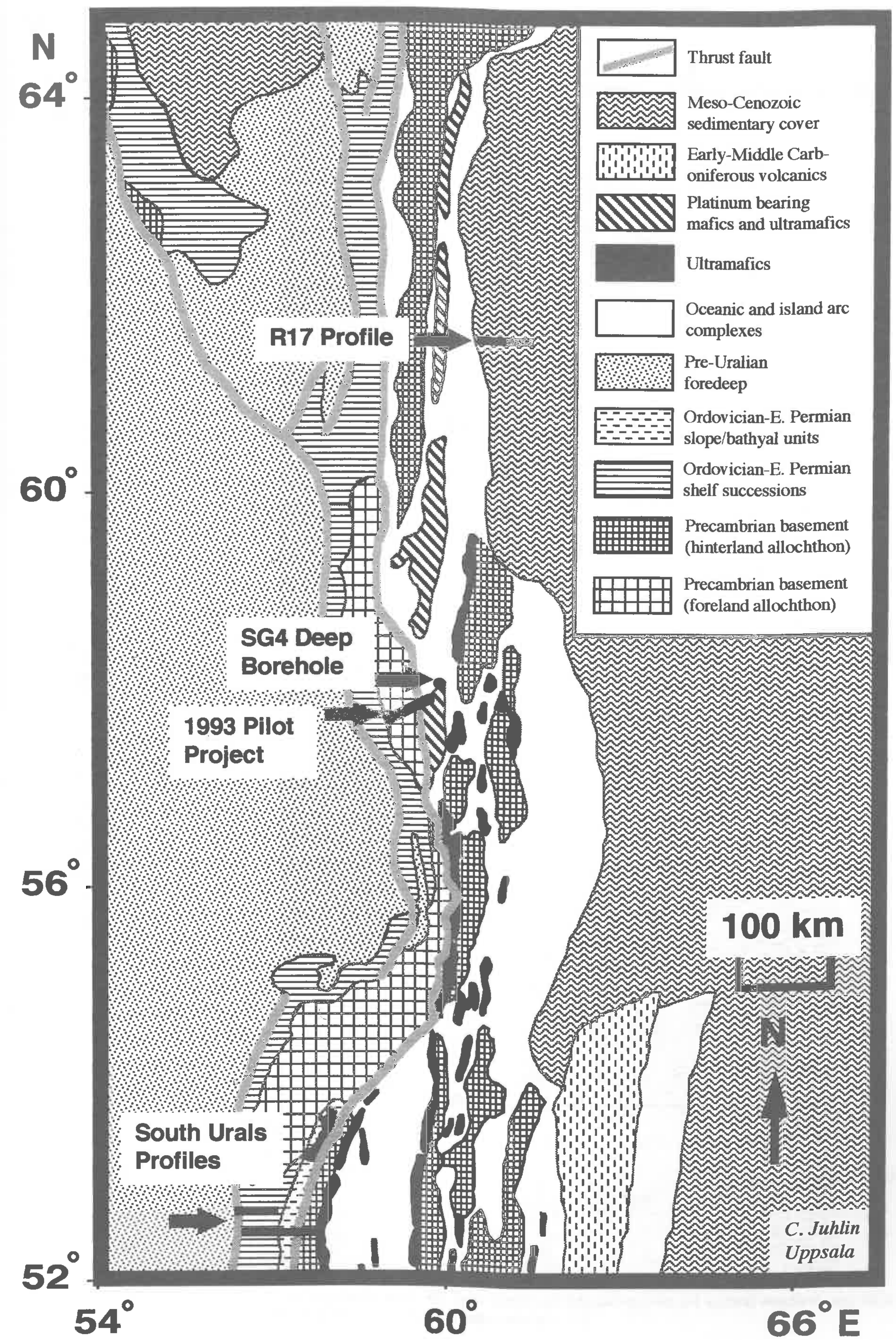

(based on Zonenshain et al. 1990)

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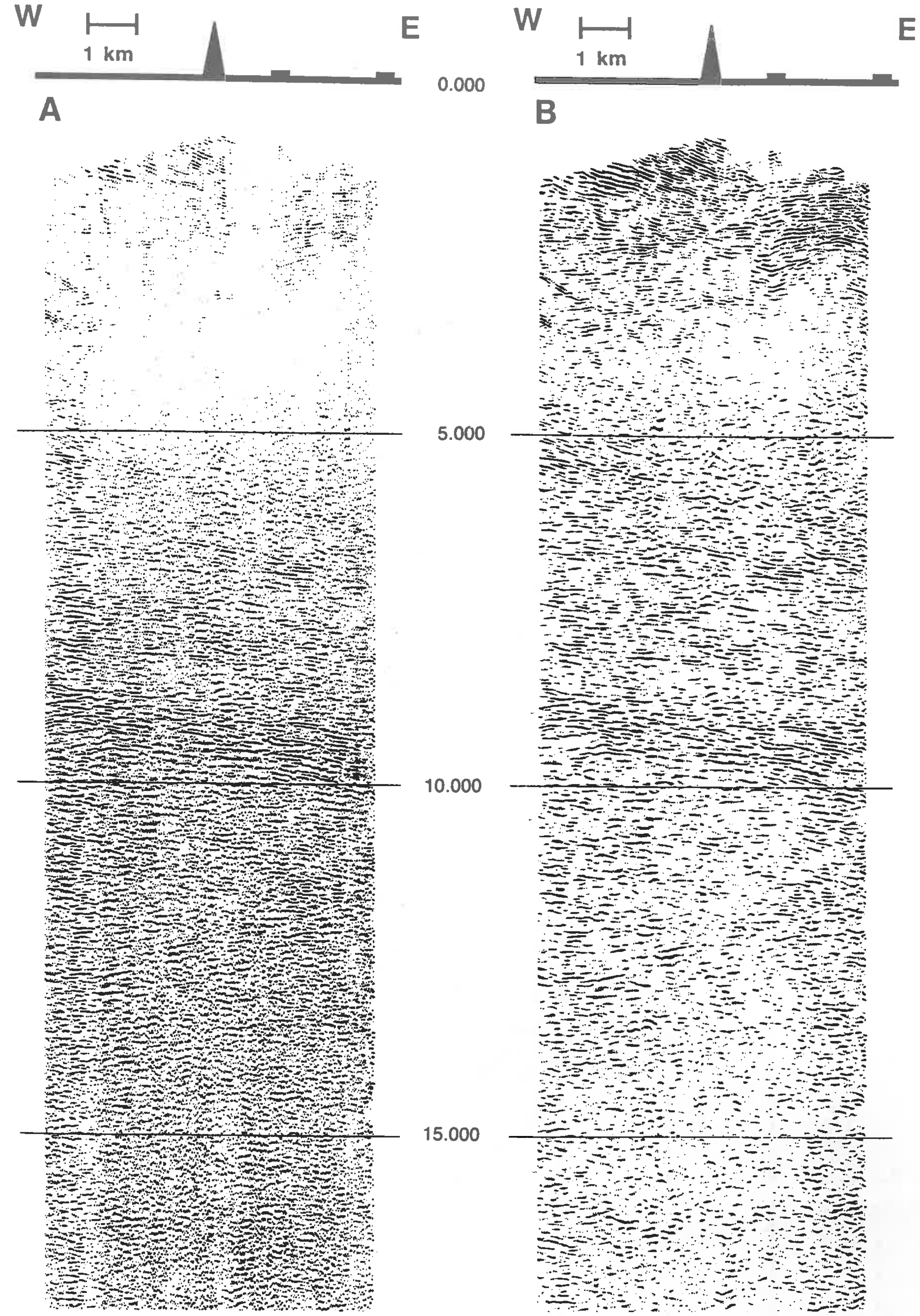

Fig. 5. Stacked CDP sections. •A. True amplitude stack. •B. Trace amplitude balancing over a 4 second window, and with a 5 trace coherency filter applied. Vertical to horizontal scale is approximately 1:2.

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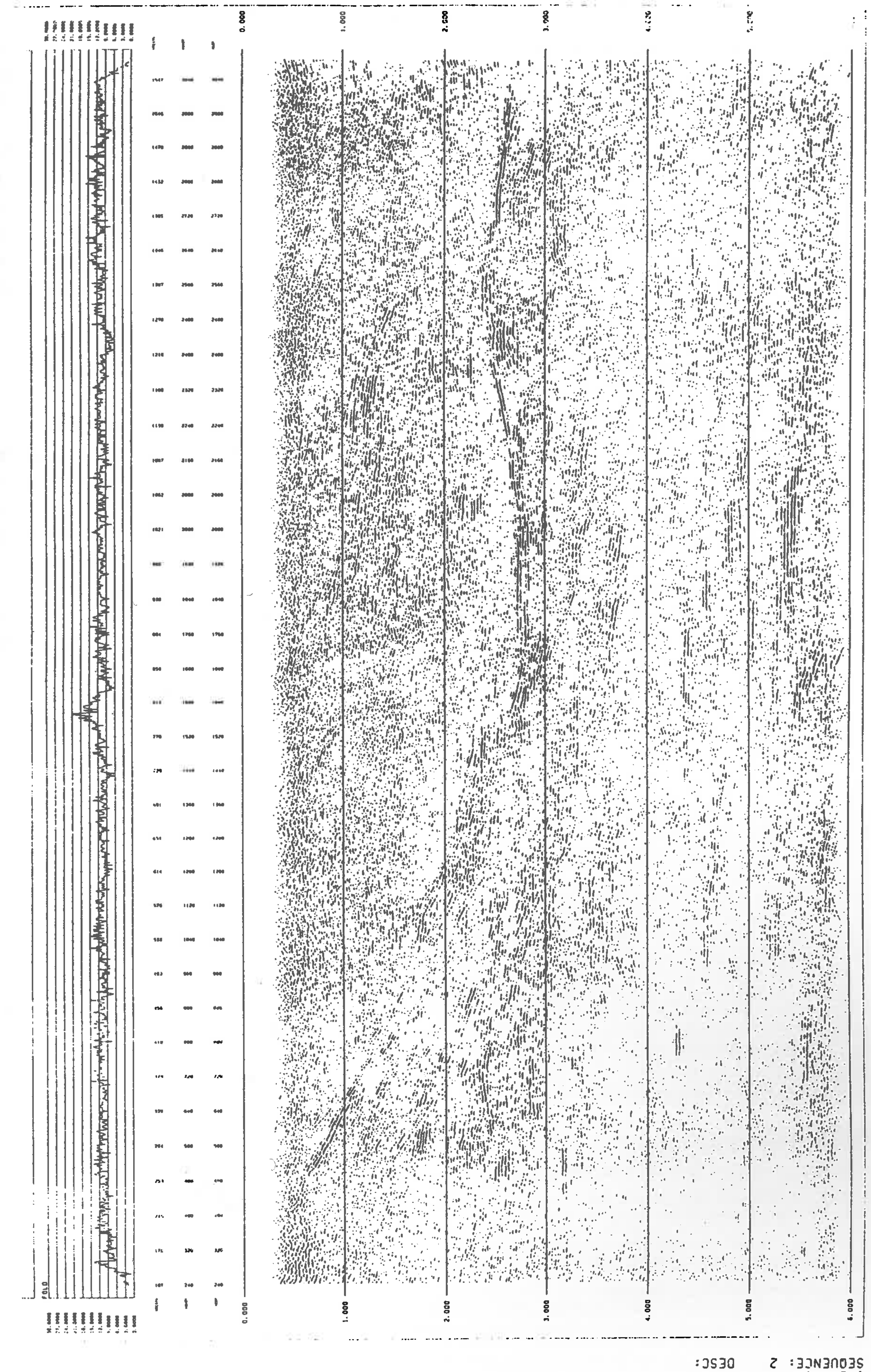

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Swedish-Russian Reflection Profiling: ESRU1993

The 1993 project consisted of acquisition of a 15 fold CDP seismic reflection profile beginning about 10 km south of the SG-4 borehole in the east and extending 60 km to the southwest across the Main Uralian Fault (Fig. 20). ESRU93 was jointly funded by URALGEOLCOM, the National Research Council of Sweden, COCORP and the GeoForschungsZentrum Potsdam. Data were recorded to 35 s and have been processed to 25 s and interpreted at these three institutions (Fig. 23). The data show numerous steeply dipping reflectors in the upper 15 km and more sub-horizontal ones deeper down. Steep reflectors correlating with the surface location of the Main Uralian Fault dip to the east extending into the crust to at least 10 km (Fig. 24); i.e. the eastern end of the section. The crust is reflective down to below 15 s (49 km) with clear westerly dipping zones in the lower crust east of the Main Uralian Fault.

German-Russian Installation of Processing Centres 1993

Modern seismic data processing facilieties have been installed by the University of Karlsruhe at the GEON centre (Moscow) and at the BGE (Sheelite) in 1993. The purpose for these installations is according to agreements on cooperations between these institutions the digitization of the superlong-range PNE profiles and their processing and archiving at the GEON centre, and, on the other hand, data exchange and field quality control during the proposed reflection experiment at the BGE. The equipment consists at both locations of a SUN SPARC2 workstation equipped with peripherals for data input and output and the interactive seismic processing system FOCUS (DISCO), and, linked by Ethernet, 2 486-Personal Computers with peripherals and software specified in Fig. 25.

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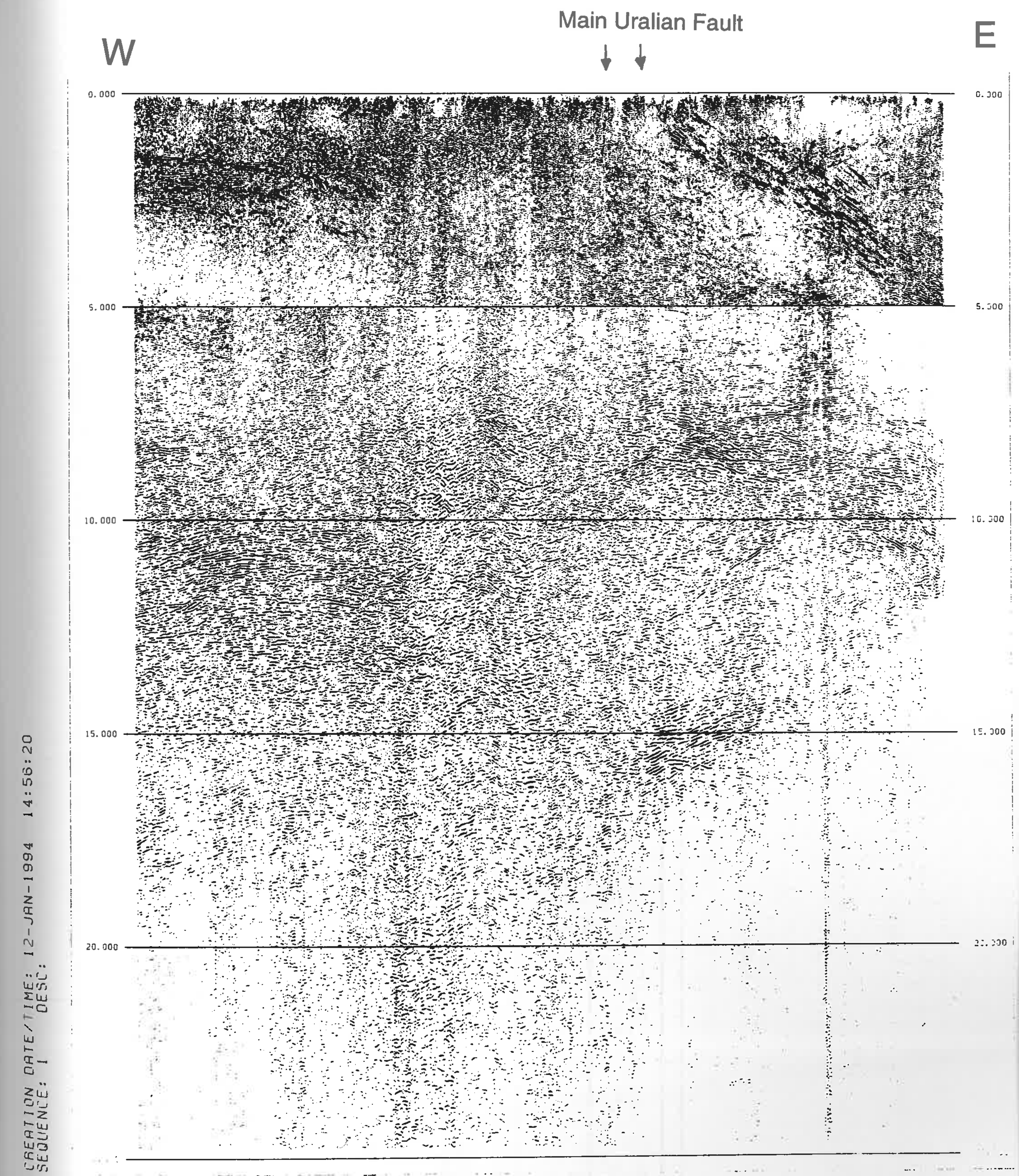
Fig. 23: Stack section of the ESRU93 profile. For location see map in Fig. 20 (C. Juhlin, pers. comm.)

Fig. 24: Migrated section of the upper part of the ESRU93 profile (C. Juhlin, pers. comm.). Note particularly the high resolution due to a frequency band of 10-120 Hz and the strongly dipping reflectors which can be traced closely to the surface correlating with the MUF.

Fig. 25: Computer configuration with hardware, peripherals and software, installed at GEON (Moscow) and BGE (Sheelite).



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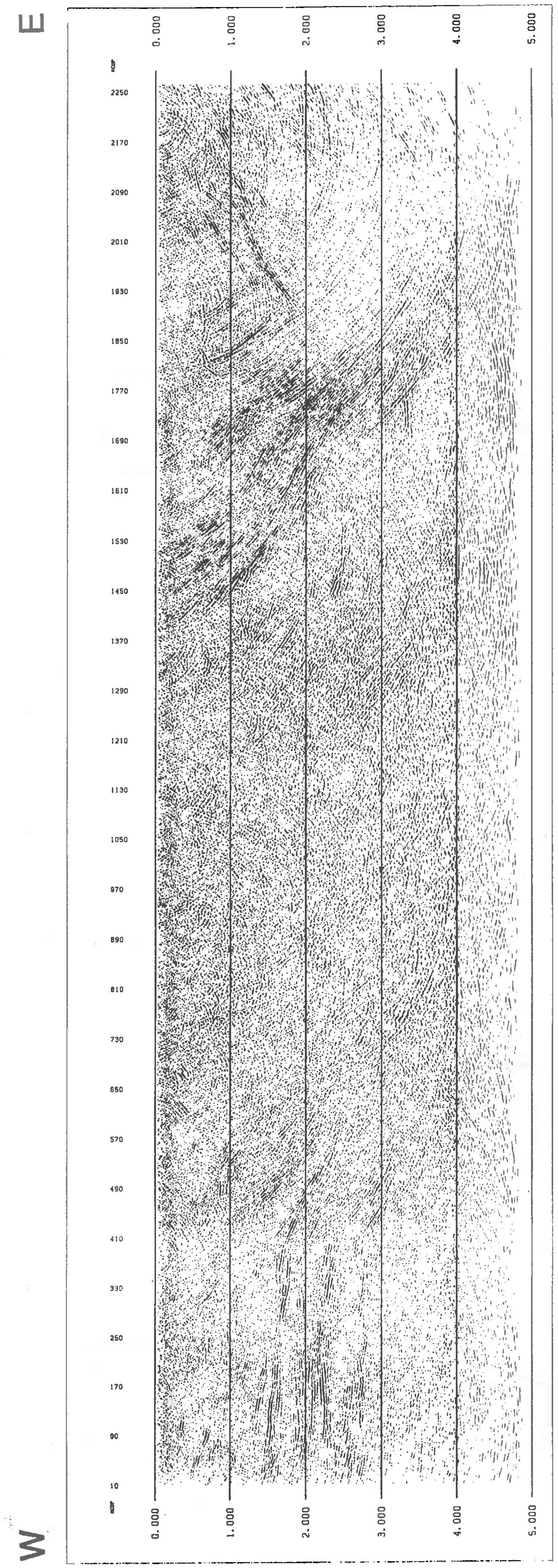

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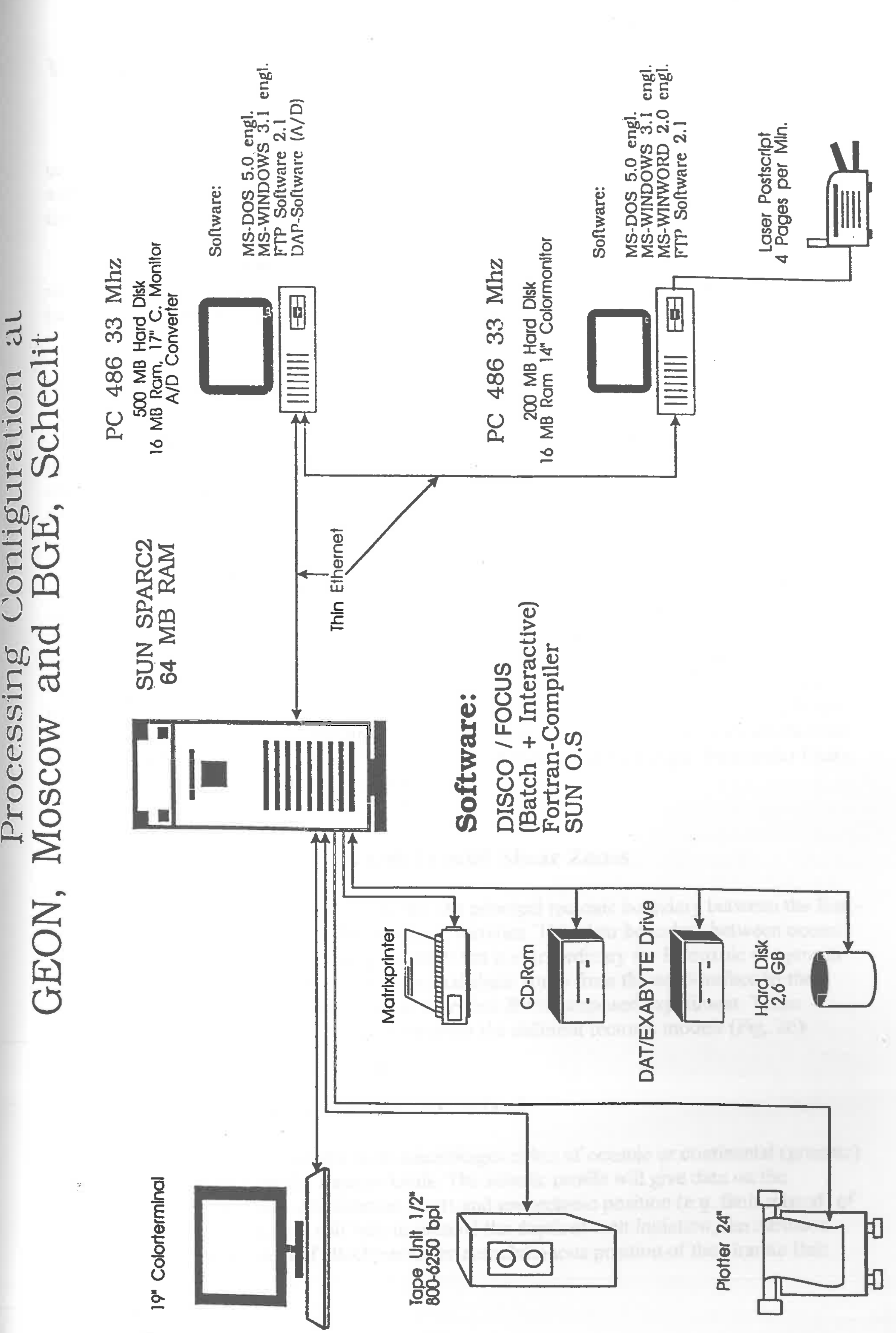

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V Objectives

The proposed deep seismic profile will image the structure of the orogen, help to unravel the tectonic evolution and distinguish between different tectonic models. The crustal architecture is the primary input to the quantification of orogenic processes and restoration of the crustal pathways.

Present knowledge of surface geology and shallow seismic images is consistent with various alternative tectonic models (Fig. 26). The main objectives listed below assume a 500-km-long profile through the South Urals as shown in Fig. 27.

(1) Crustal Root

Regional DSS profiles reveal a pronounced root along the whole orogen with a thickness of up to 65 km. This crustal thickness is anomalous in comparison other Paleozoic orogenic belts (Appalachians, Caledonides, Variscides). Present knowledge of the evolution of orogenic roots show such a feature to be short-lived due to late-orogenic collapse and reequilibration to normal crustal thickness.

The exact geometry of the root in relation to the morphogenic axis of the orogen is not yet known, but is a key to its dynamic interpretation. The nowadays morphological expression of the Urals has developed after Mesozoic transgression. The current topography is a result of Tertiary uplift. If the root is symmetric with respect to the topography, the obvious conclusion would be that the root has been formed in late Mesozoic or Tertiary times and that the uplift is the isostatic response to it. If on the other hand the root is shifted to the east, underneath the accreted island arcs, it must be a remnant of the Paleozoic collision. The geometry of the root and its relation to the morphogenic (Post-Mesozoic) Urals and the geologic (Paleozoic) Urals provides a crucial hint of its time of formation.

(2) Main Uralian Fault and Crustal Shear Zones

The Main Uralian Fault (MUF) forms the principal tectonic boundary between the East-European craton and the Uralian Paleo-oceanic terranes. This clear boundary between oceanic and continental assemblages extending for 2000 km is extraordinary for Paleozoic orogens in the world. To image this suture and other crustal shear zones from the near-surface to their maximum extension into the crust is a main objective of the proposed experiment. These images will provide a strong discriminant between the different tectonic models (Fig. 26).

(3) Magmatic Bodies in the Hinterland

Large volumes of magmatic rock assemblages either of oceanic or continental (granitic) character are widespread in the Eastern Urals. The seismic profile will give data on the geometry, the volume, inner stratification, roots and geotectonic position (e.g. fault related) of the magmatic bodies. The data will help to unravel the depth of melt initiation, the intrusion mechanisms and the problem of allochtonous or autochthonous position of the Granite Belt altogether.

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(4) East-Uralian /Trans-Uralian Boundary

The Troitsk Fault Zone is a rectilinear sub-vertical crustal wrench fault which can be traced over 2000 km. This fault is a major boundary between the East-Uralian granite-rich and micro-continental domain and predominantly volcanic arcs of the Trans-Uralian Zone. We want to image the crust on both sides of this fault to study its geometry and to compare the crustal structure on either side.

(5) Trans-Uralian High-Pressure Zone

A major west-dipping shear zone containing high-pressure rocks and oceanic assemblages is reported from the easternmost Uralian outcrops. Imaging this potential suture to greater depth will determine the degree of bivergerce of the orogen and the geometry of structures presently covered by Mesozoic sediments.

(6) East-European Craton and Foreland Basins

In order to determine the extent of subduction of the East-European continental crust below the Urals we need to acquire the seismic signature of the undeformed deeper crust west of the orogen. In addition, the image of the structure of hydrocarbon-rich foreland basins, and the thin-skinned tectonics in the sedimentary cover are a basis to quantify orogenic shortening in time and space.

(7) Mantle Structure

Analysis of long-range PNE-refraction profiles indicate the Upper Mantle to be heterogenous below the Northern Urals. By recording far-offset large explosive sources we want to record reflected energy from such heterogeneities down to 200 km and deeper. This will allow us to trace possible deep shear zones into the mantle and to distinguish between the lateral versus vertical heterogeneity in the Mantle as well as to model the orogenic and post-orogenic events involving the entire lithosphere.

(8) Neotectonics

Recent crustal movements involving high uplift rates (2 mm/y), Neogene basin formation and seismicity indicate the area to be tectonically active. The deployment of seismic stations during and after the main acquisition phase will provide data on where the seismically active zones are located. These data will be integrated into GPS measurements and stress field studies.

(9) Non-Seismic Anomalies

The seismic reflection profile will aid in interpretation of several geophysical datasets in the Urals. These include the anomalously low heat flow (20-40 mW/m^2), the short-wavelength positive gravity anomaly (approx. + 50 mGal over 100 km) embedded in a long-wavelength negative anomaly (approx. -50 mGal over 400 km), and the narrow high-conductivity zones

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adjacent to the Urals at midcrustal levels. Detailed gravity and magnetic data acquired along the seismic profile will be combined with quantitative interpretation methods to provide an independant test of models constructed from the seismic data. Targets on a variety of scales can be addressed: for example, it should be possible to confirm the location of discontinuities and the depth extent of bodies in the near surface as well as examining the nature of the crustal root.

VI Proposed Research

Two locations for the vertical reflection profile have been pursued in parallel: The Middle and the Southern profile. Both have their specific attractions. However, both of them have also their adversities. These main advantages and disadvantages are presented below:

<u>Middle Urals transect</u>

Advantages

- more geophysical data in the area, especially seismic
- crust is known to be highly reflective down to 10 s TWT
- area appears to be more seismically active
- the BGE as the main Russian partner has more experience here
- possibility of calibration with the SG-4 deep borehole

Disadvantages

- surface geological exposure is poor, mostly sampled by numerous shallow drillholes
- section is in a significantly squeezed and shortened part of the orogen
- field conditions (swamps!) require the profile to be shot in two seasons
- access by roads is more limited

<u>Southern Urals transect</u>

Advantages

- better surface geological exposure
- geological section is the most complete
- each geological zone is wide enough to allow correlation with the seismic image
- better access by roads
- profile can be completed in one season

Disadvantages

- stronger agricultural activities

Based primarily on geological considerations the Southern profile has been given highest priority and data should be acquired first in this area. However we still feel that the Middle Ural profile is of great geodynamic interest and recommend that future activity be focussed in this area also. This will involve extension of the 1993 ESRU pilot profile to the East and West as well as other geophysical experiments related to the deep borehole SG-4.

Seismic Reflection Profiling

A 500 km long **near-vertical** seismic reflection profile using state-of-the-art data acquisition is considered to be the **core** of the proposed research. For the southern option the EUROPROBE working group concluded that 500 km was necessary to achieve the above stated objectives. Use of state-of-the-art equipment (24 bit digitization, telemetry data transfer, minimum 400 recording channels) and the proposed field parameters will provide high-quality images of the upper crust and signal penetration into the upper mantle. This will allow correlation of surface geology with the seismic image of the entire crust and possibly the upper mantle, as shown by the LITHOPROBE program over the Grenville Front, COCORP over the Appalachians, DEKORP over the Rhenish Massif. Results from the Swiss program NFP20 in the Alps show how to combine high-resolution in the upper crust (down to 20 km) with deep signal penetration (Figs. 28, 29, Valasek et al., 1991). Based on these results we propose the field parameters as given in Table 1.

Profile length	**500 km**
Source	**Explosives in drillholes**
Shotpoint spacing	**200 m**
Number of shotpoints	**2500**
Explosive size	**30-50 kg**
Receiver spacing	**50 m**
Number of recording channels	**400**
Spread length	**20 km**
Spread type	**symmetric 10 : 10 km**
CMP coverage	**50**
Frequency range (expected)	**2-150 Hz**
Record length	**30 s (90 s for large shots)**

Table 1. Proposed field parameters for main profile.

With respect to the high resolution near the surface, 50 m receiver spacing and 200 m shot spacing are considered to be the maximum allowable. In addition to these parameters, we require a high-frequency source, such as dynamite of small charge sizes (30-50 kg, in drillholes typically 20-30 m) (frequencies 2 - 150 HZ or higher, compare Fig. 24). Given our past experiences over the last 10 years and local conditions in the Urals we recommend at this time that explosives be used as the source.

In order to ensure signal penetration below 30 km (expected Moho depths 50-60 km and deeper upper mantle structures) we require additional large explosives (200-500 kg) to be fired every 20 km for every 20-km-moveup of the spread up to offsets of 200 km (Fig 30). These long-offset observations will provide 5-fold coverage of the deeper crust and upper mantle and provide lateral and vertical velocity control down to the Moho. The offset range of 0 to 200 km allows to trace reflections from pre-critical to post-critical distances and thus, to investigate the nature of deep crustal discontinuities. This **Coincident Wide-Angle Seismic Profiling** will also allow for the integration of the large body of existing Russian DSS datasets.

The above acquisition strategy consisting of near-vertical and coincident wide-angle recording will be carried out by a single industrial contractor and forms the **core** of the seismic field experiment. The long active spread (20 km), the desired high resolution, the great

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penetration depth (100 km or more) and the expected high dynamic range of the signals (near-offset in conjunction with wide-angle acquisition on the same system) requires that the most modern equipment be used.

Complementary Seismic Studies

The studies proposed here will give valuable data in the area of the reflection profile without causing any delays in the main line acquisition. The most important of these experiments are:

1) **cross-line recording**, stationary spreads perpendicular to the main profile every 10 km will provide 3-D control of reflections observed on the main profile. Five such spreads moving up in 10-20-km intervals will be active during recording (Fig. 31). Fig. 32 shows a time slice as an example from DEKORPs MVE90 profile where this technique has been successfully implemented to detect the true dip in three dimensions of certain target reflectors. The optimum configuration of these cross-line spreads should be kept flexible (length, spacing) depending on simulations during the field acquisition according to results obtained from the main profile and according to the geological situation (dip of faults, e.g. MUF).

2) **three-component shear-wave recording**, additional stationary spreads parallel to the main profile using three-component receivers (2-4.5 Hz) will record shear-wave energy and help constrain the physical properties of the reflectors in the crust. These spreads will consist of 16 to 40 stations spaced at 50 m intervals and located every 20 km along the profile (Fig. 31).

3) **DSS-tomography-seismicity**, deployment of remote seismic stations during the main experiment and after its completion (3 months) will give tomographic images and information of the seismic activity in the area of the profile. The active part of the experiment (DSS) consists of recording of 6 strong shots (3 - 4 t) by 250 three-component-stations distributed along the whole line during 1 week (Fig. 33) und will provide laterally and vertically varying velocity information into the Upper Mantle (Fig.33).

Potential field participants in the above experiments are BGE (Sheelite), GEON (Moscow), Universities of Glasgow, Grenoble, Karlsruhe, Uppsala, the GFZ (Potsdam). The equipment pool provided by these institutions consists of 5 PROGRESS systems (48 ch), 4 DFS-V systems (48-120 ch), 1 SERCEL 348 system (80 ch), 310 digital 3-ch recorders (100 CEIS-ESPACE, 150 PDAS,REFTEK,MARS88; 60 CHERIPACHA).

Fig. 26: Alternative, speculative tectonic models of the Urals.

Fig. 27: Location map of the Southern Urals transect

Fig. 28: Results of the eastern NFP 20 traverse through the Alps. Top: Multifold Vibroseis measurements, Bottom: single-fold dynamite soundings. The Vibroseis data provided a high-resolution image of the shallow levels compared to the dynamite data. In contrast, the dynamite data provided much more prominent deep crustal information. From Valaset et al., 1991.

Fig. 29: Schematic crustal cross-section showing the main features of the Alps and adjacent regions. The section is based on an integration of surface geologic information and the combination of the NFP20 and EGT seismic reflection data. In the seismic sections on top of the figure a comparison is made between an explosive seismic section (left) and a Vibroseis section (compare fig. 28) (Valasek et al., 1991).

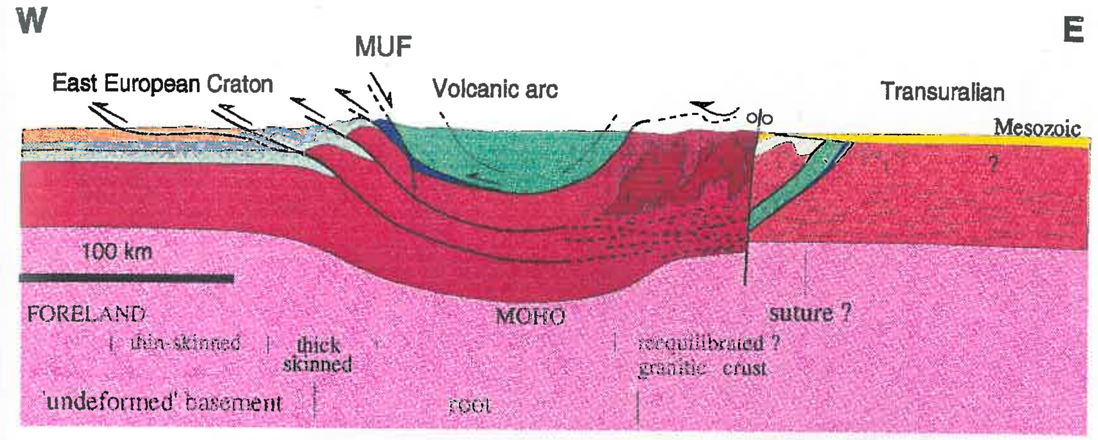
Fig. 30: Coverage scheme of the coincident wide-angle measurements

Fig. 31: Configuration scheme of complementary seismic measurements (cross-line and three-component recording).

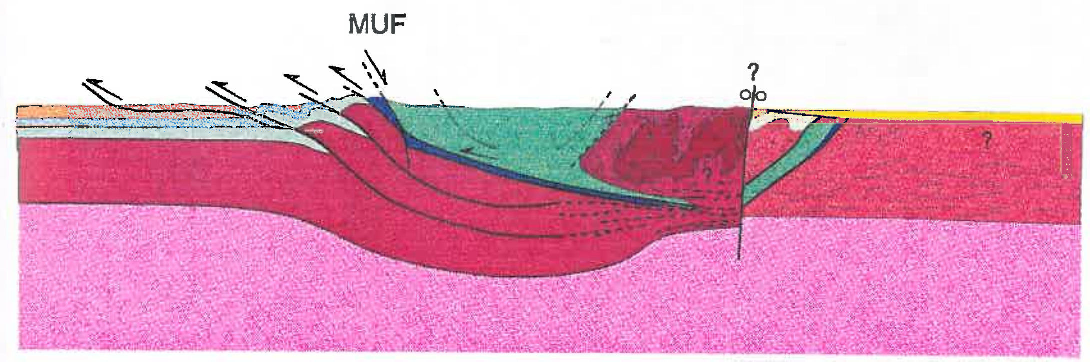
Fig. 32: Time slices at 550 ms, 700 ms, 850 ms, 1000 ms obtaining from 3D-processing of cross-line recordings during the DEKORP MVE90 experiment (Univ. of Karlsruhe).

Fig 33: Configuration scheme of the complementary DSS experiment. Six shotpoints with 3-4 t of explosives each and about 250 3-component stations are deployed along the 500-km-long line.

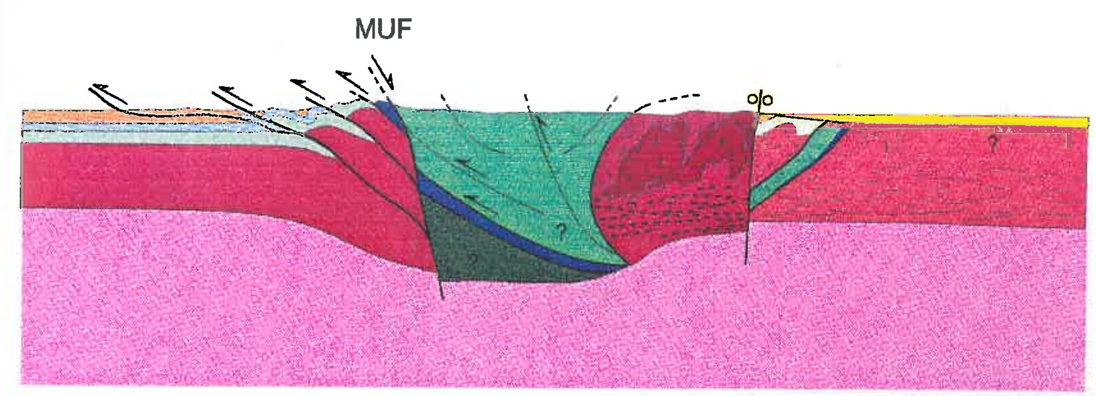
LITHOSPHERIC MODELS ON THE NATURE AND GEOMETRY OF THE URALIAN CRUSTAL ROOT AND MAIN URALIAN FAULT ZONE (MUF).



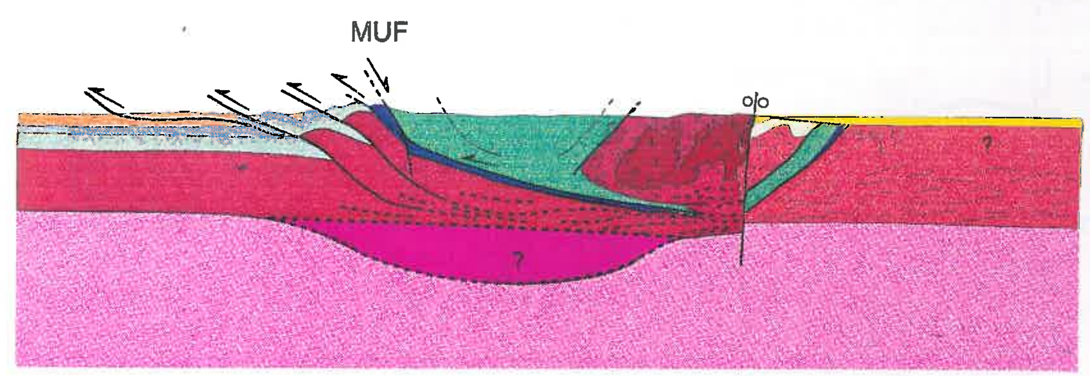
a) Subduction of the East European Craton and stacking account for crustal thickening. MUF as a shallow and refolded crustal shear zone. Oceanic and arc terranes allochthonous.



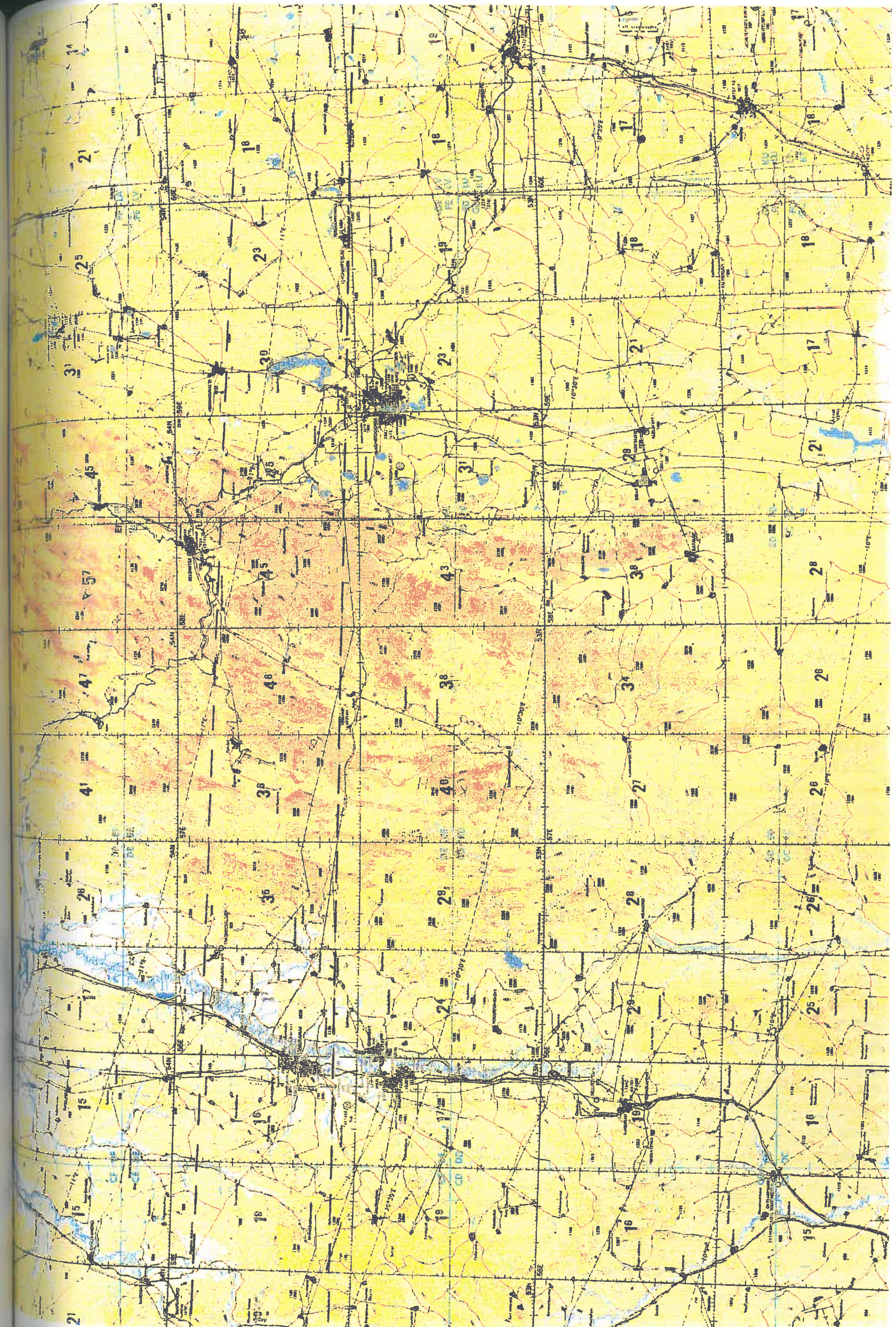
b) MUF as a rooted suture zone, backthrusting in the hinterland



c) MUF as a steep dipping crustal shear zone. Root consists mainly of a crustal block of oceanic and arc terranes accreted during Lower to Middle Paleozoic.



d) Orogenic crust of normal thickness. Root consists of underplated anormal light mantle material.



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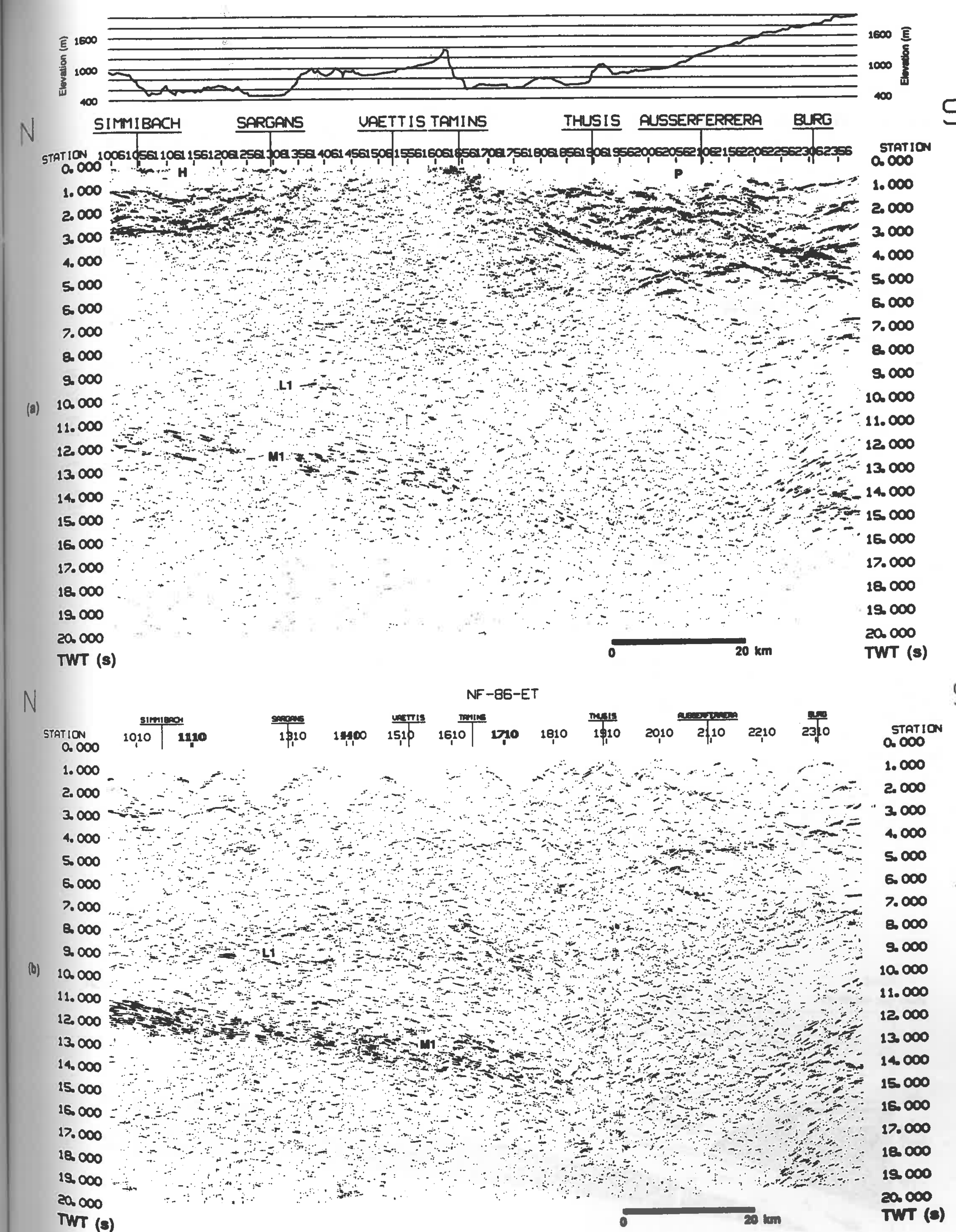

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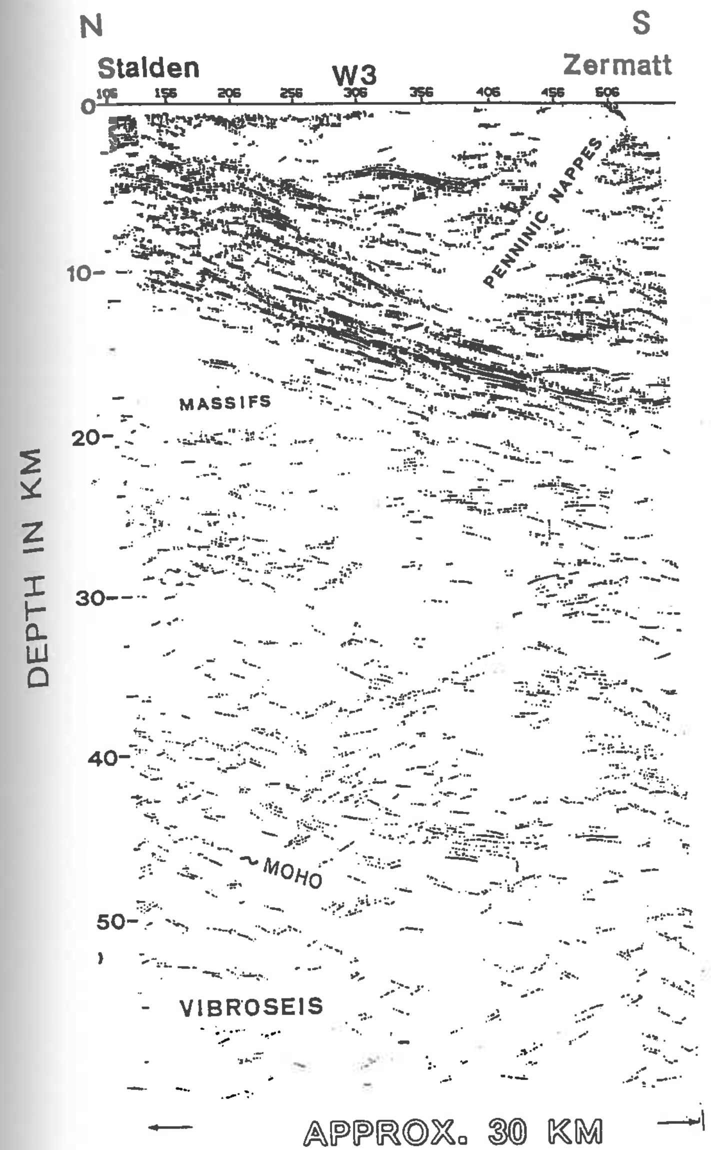

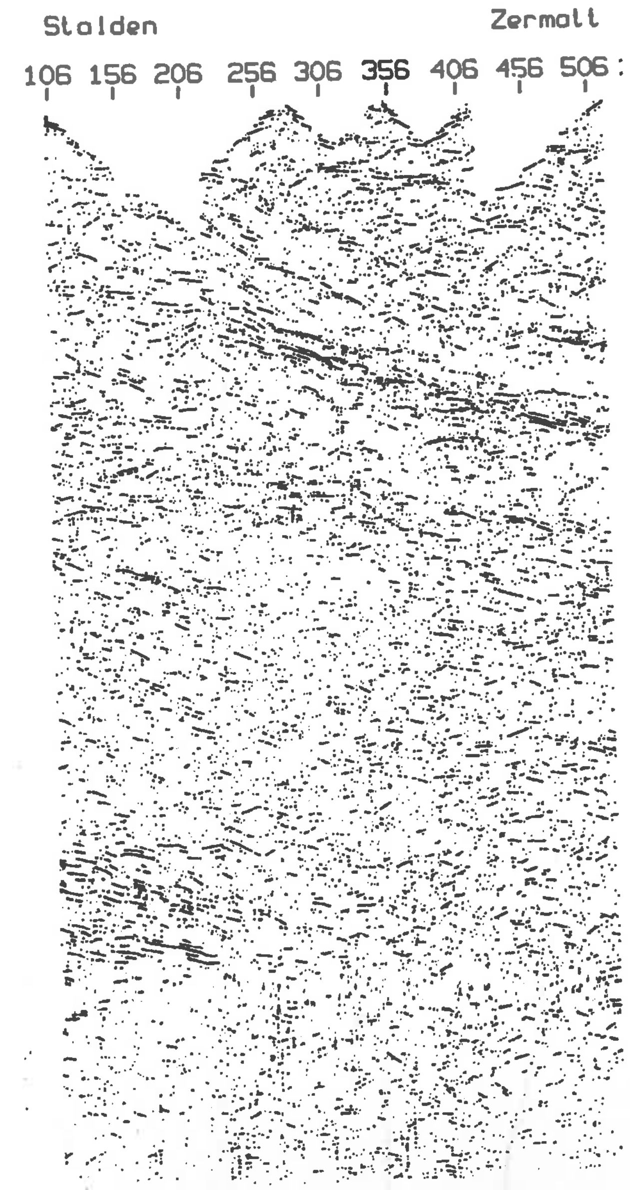

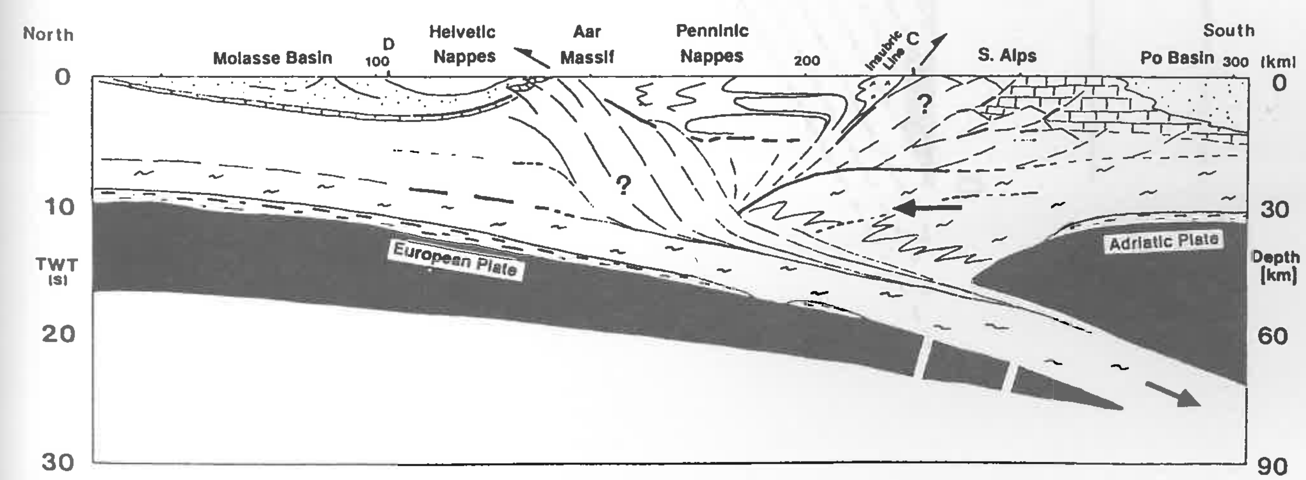

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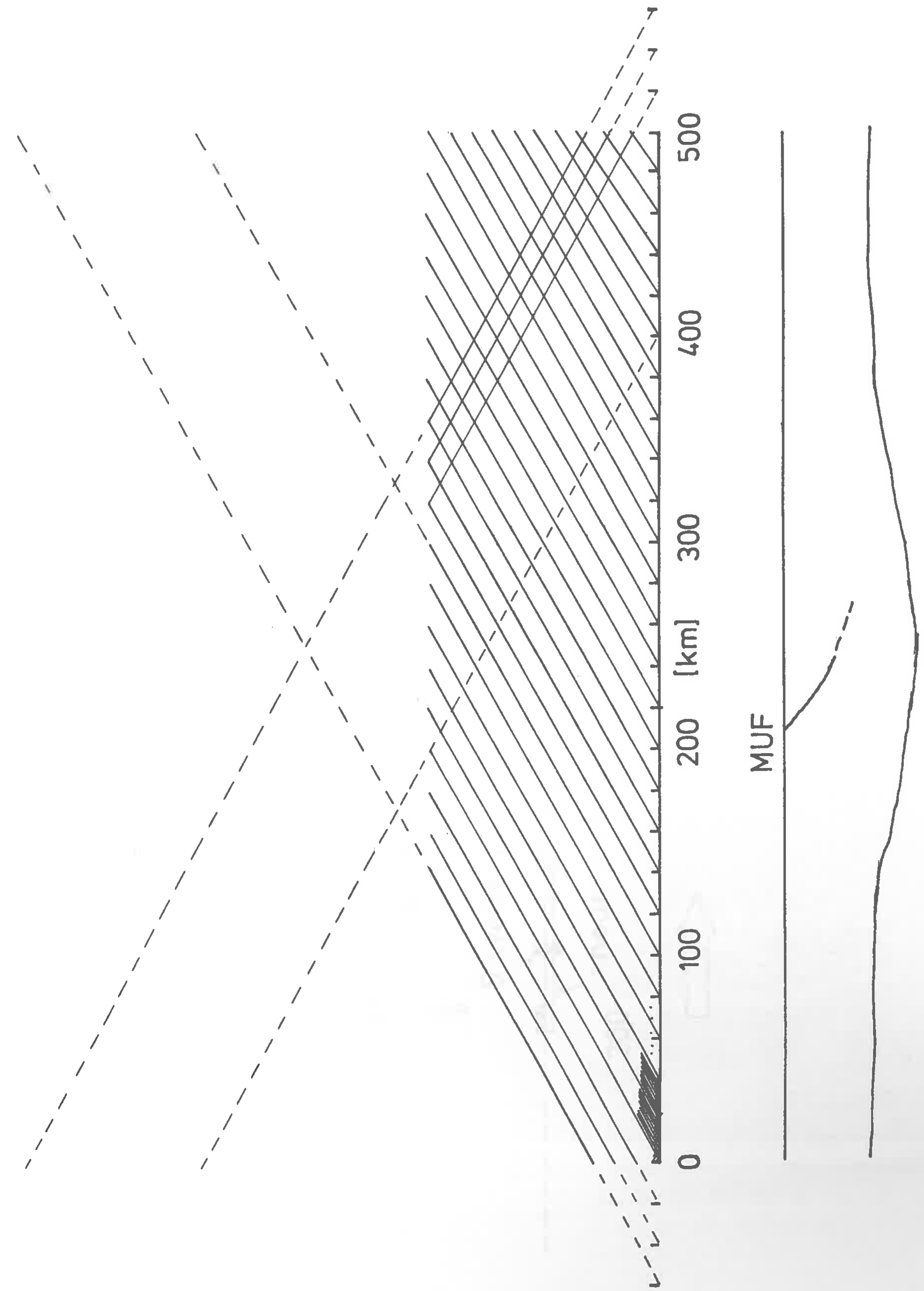

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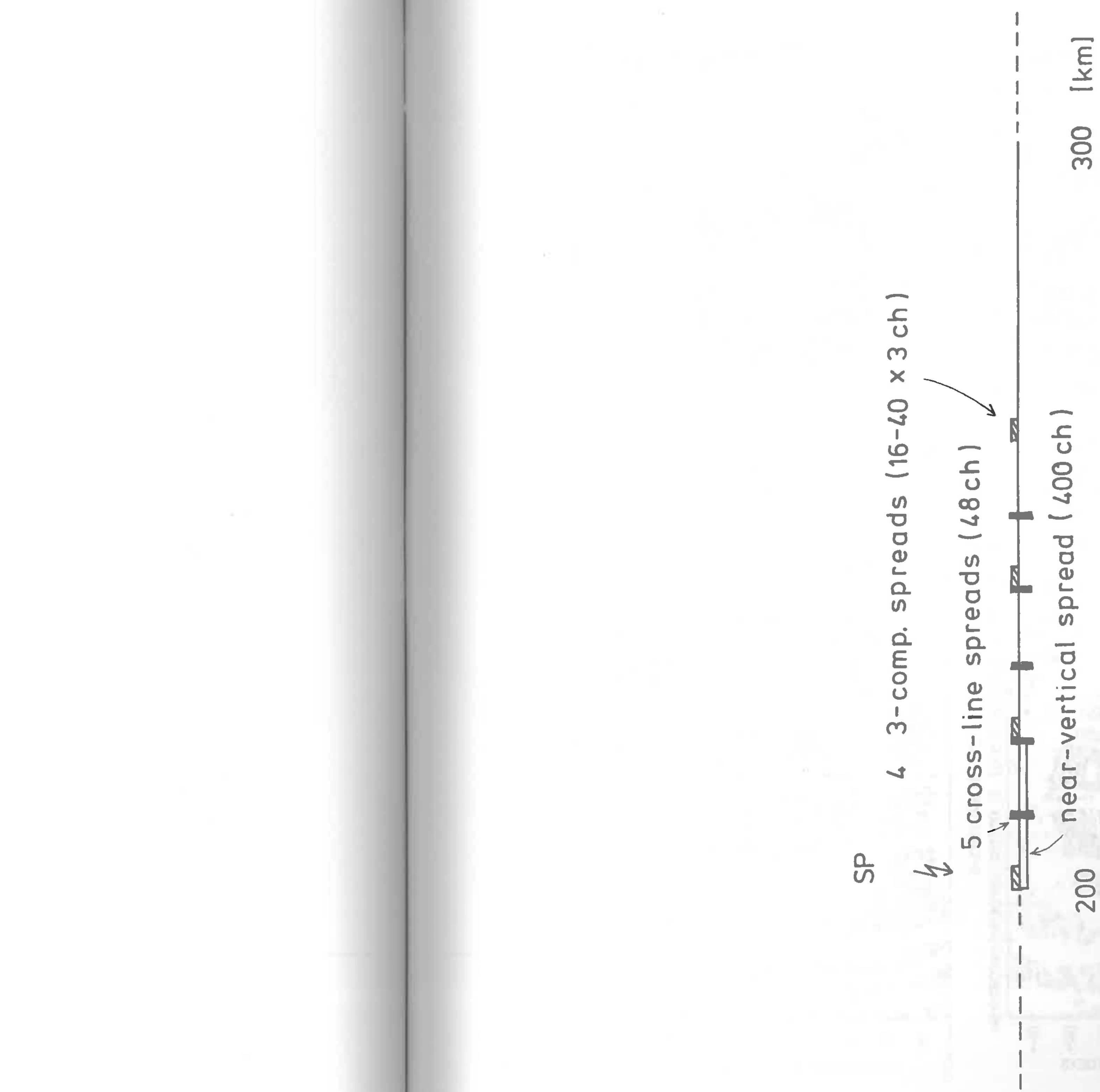

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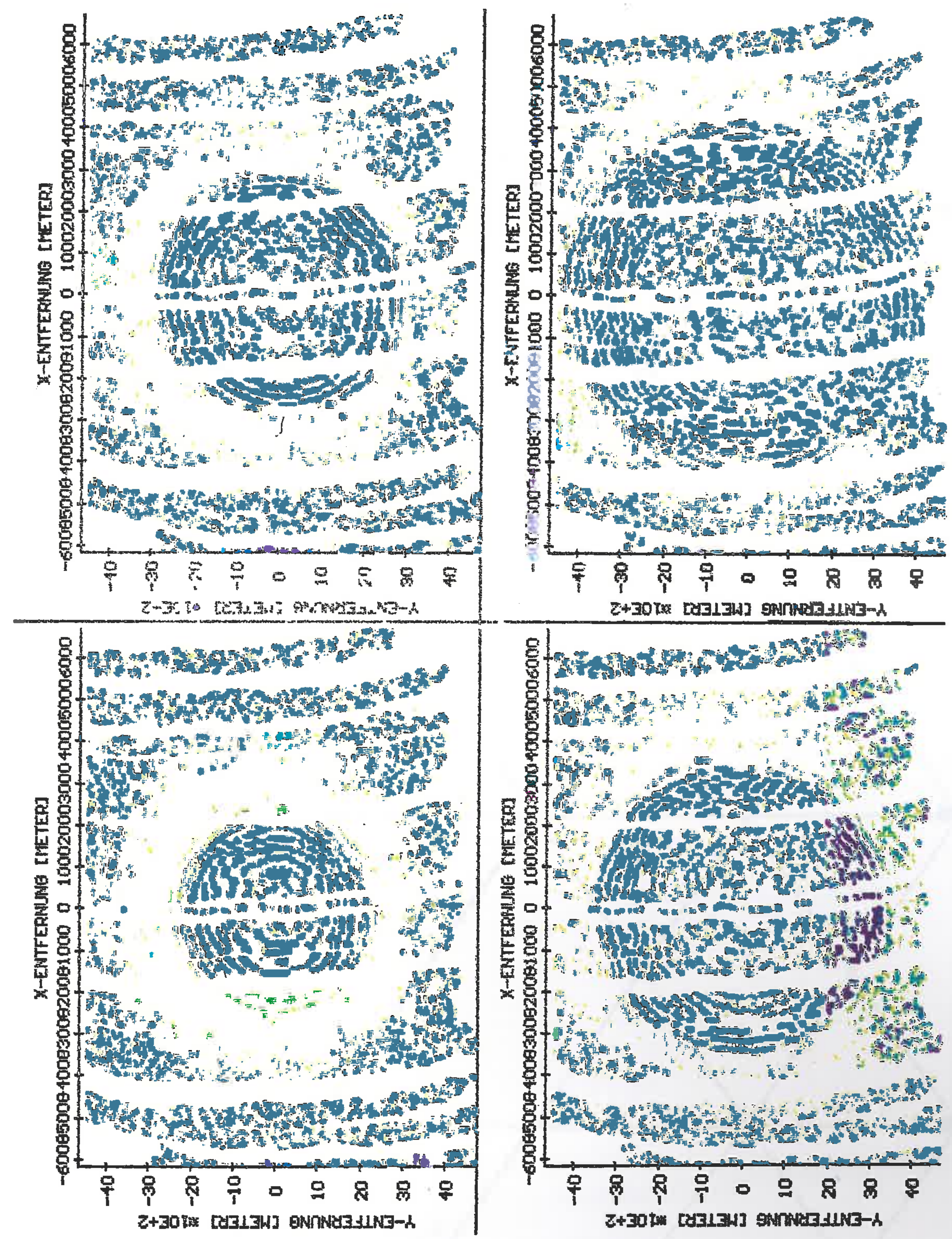

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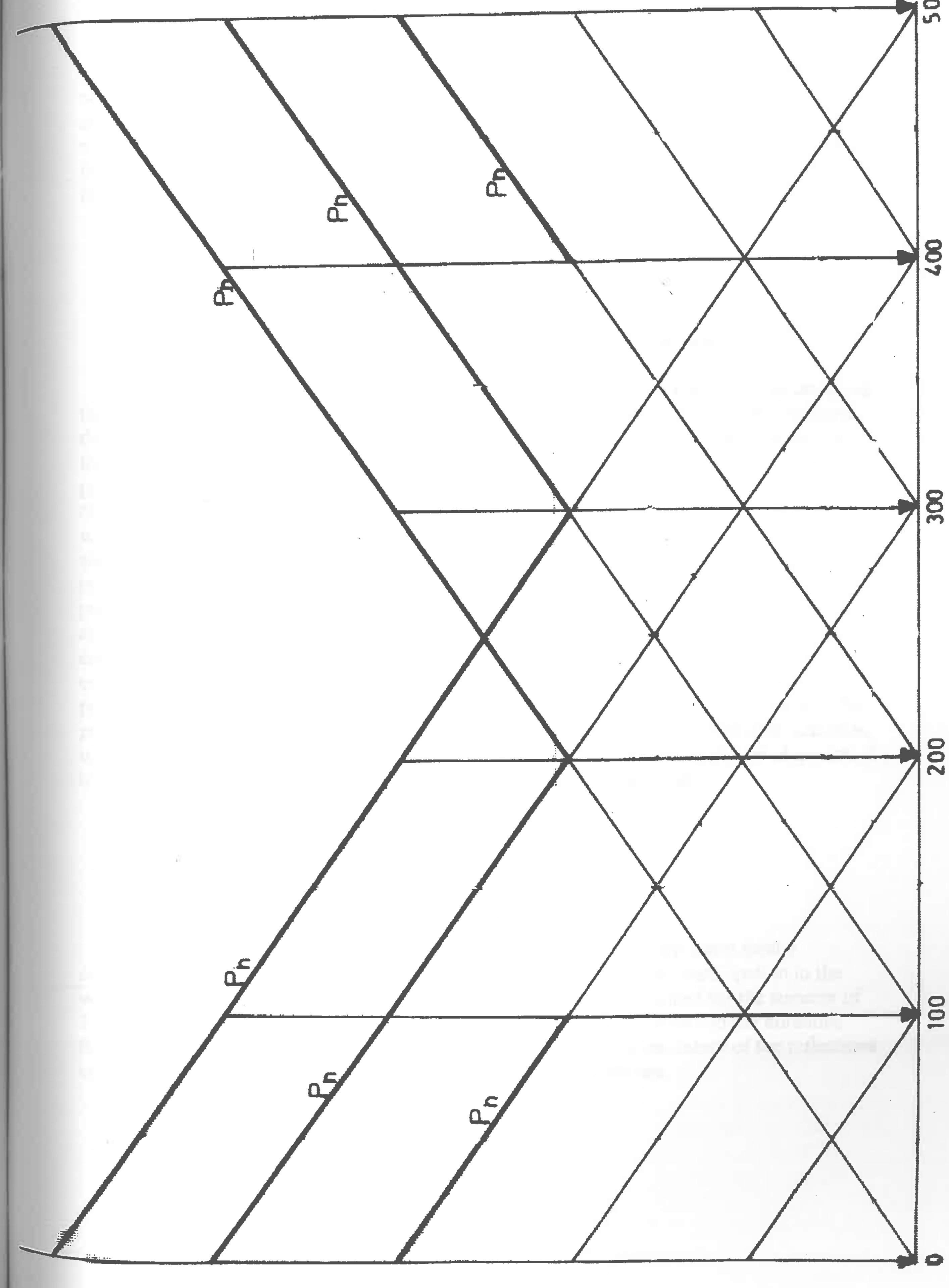

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Interdisciplinary Studies

The Urals project aims to achieve a fully integrated study of different experiments and science plans that will provide a model of the structure and evolution of the belt constrained by all the available datasets. These experiments and science plans were defined in several workshops that constituted an opportunity to review the previous data and identify priorities for new investigations. The following is a brief summary of the specific subprojects that are intended to accompany the main experiment.

Potential field studies and integrated modeling.
M.K. Lee & G.S. Kimbell, British Geological Survey, U.K.
V.A. Shapiro, Institute of Geophysics, Ekaterinburg, Russia
Y. Menshikov, Bazhenov Geophysical Expedition, Sheelite, Russia

Regional gravity and magnetic data are available for the Urals belt and large areas are thought to be covered by detailed surveys at a line spacing of around 500 m. This extensive database offers a unique opportunity to study the internal structure and tectonic evolution of the orogen. The first part of the project will aim to compile available digital data and to generate a suite of modern image-based maps of the Urals belt. These will be used to identify the principal tectonic elements and study the heterogeneity and segmentation of the belt. They will also provide an important structural framework for other EUROPROBE projects. If suitable data are available, detailed potential field imaging will be carried out in the areas of the pilot seismic profile in the middle Urals and the proposed major trans-Urals seismic reflection profile in the southern Urals. Integrated gravity/magnetic/seismic modelling will be undertaken along the seismic lines in order to define models of the shallow and deep crustal structure constrained by all three datasets. Quantitative potential field interpretation will be used to extend models of concealed geology away from the seismic profiles, employing constraints provided by geological mapping, borehole evidence and other geophysical experiments. The project will also provide an opportunity, in collaboration with other EUROPROBE activities, to relate the structural framework and tectonic evolution of the orogen to the development of hydrocarbons and minerals resources in the Urals and surrounding areas.

Reflection seismic imaging and structural interpretation
C. Juhlin, Uppsala University,
S. Kashubin, BGE, Sheelite,

Plans are to continue the ESRU profile about 60 km to the East using similar acquisition parameters as in 1993 with joint Swedish and Russian field participation in the winter of 1995. Vertical seismic profiling in the SG-4 borehole is planned for the summer of 1994, as well as an extension of the ESRU profile to the north to connect to the borehole. Seismic modelling of the data collected will help us to understand the nature of the reflections we observe and in interpreting the geological and tectonic conditions.

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UWARS - Uralides wide-angle reflection seismics and related teleseismic studies
F. Thouvenot, University of Grenoble,
S. Kostiuchenko, GEON, Moscow

Experiments designed to map deep seismic reflections beneath the Middle Urals and check the existence of a crustal root (wide-angle reflections from seven shotpoints complemented by a passive teleseismic experiment along a 600 kilometre-long profile). The inversion of these teleseismic data will provide a velocity model of the lithosphere/asthenosphere beneath the Uralides.

Dynamic stratigraphy and sequence analysis of Uralide Lower Paleozoic basins
B.D. Erdtmann, W. Müller, Techn. University Berlin
Maslov, Ekaterinburg

During pre-orogenic depositional history the eastern margin of the East European Platform formed a passive continental margin, whereas the Early Paleozoic of the juxtaposed Siberian and Kazakh plates formed initial tensional rifts, but during Late Paleozoic these regions were transformed into active collisional margins. A series of system tracks formed reflecting various cycles of marine on- and offlaps are recognized and the timing of these depositional cycles can be well controlled by a dense network of both biostratigrafic and paleofacies indicators. The Paleozoic accretionary collision of the Urals, of the Kazakh, Siberian, and East European Platform may be reconstructed, with regards to the basin dynamics, by restoration of the depositional history of its margins.

Dynamic biogeography during the Mid- and Late Paleozoic convergence of the Urals
R. Feist, University of Montpellier,
Ancygin, Ekaterinburg

An analysis of the evolution of plate convergence during the Late Paleozoic until final accretion of the Uralides by calculating similarity factors of facies dependent and biostratigraphically controlled biota from formerly separated blocks.

Structural analysis of the footwall to the suture of Southern Urals
J. Alvarez-Marron, A. Peréz-Estaún, D. Brown, Oviedo University
Rappoport, Ekaterinburg

This investigation intent to produce balanced cross-sections of the Southern Urals, from the Pre-Ural foredeep to the West-Ural zone and to determine the structural evolution of these external areas. The integration of detailed structural analysis and the interpretation of existing seismic lines from those two zones will allow to estimate the crustal shortening, the sequence of deformation and the location of the sole thrust and different detachment levels within the sedimentary pile. All these informations, together with data from the deep seismic reflection profile to be acquired, will provide the complete crustal structure of the footwall to the main suture of the Urals. This crustal section may be restored to the undeformed state.

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Hinterland deformation in the Uralides and accretion of "microcontinents"
P. and E. Bankwitz, GFZ Potsdam,
Koroteev, Ekaterinburg

In the hinterland of the South Urals, built up by the area of the back arc (Magnitogorsk Zone) and the Granite Belt of the East Urals Megazone, geological studies will be focussed on the deformation analysis (planar and linear fabrics) in granites and their host rocks. The sequence of deformation and its intensity will be determined, including strain analysis and kinematic studies of the tectonic transport. Because of the excellent preservation of the Urals orogene without later overprinting, the polyphase intrusion and deformation in one of the largest granite belts of the Earth can be a key area to decipher the late Palaezoic plate tectonics events. These studies improve the knowledge on collisional processes. In connection with the planned deep seismic profiling crossing the South Urals, the field work will support the later geological interpretation of the seismic data.

Kinematic history of the Main Uralian Fault.
H. Echtler, GFZ Potsdam
K. Ivanov, Ekaterinburg

This research will examine the kinematics of the Main Uralian fault and related structures in the Middle Urals and relate the tectonic fabrics with the metamorphic conditions and deformation processes. Other targets are to determine the age of different movements on the Main Uralian fault and to study the geometry at depth by seismic reflection data. The final objective is to address the role of orogenic collapse or crustal re-equilibration, such as has been documented in numerous other orogens. Critical evidence in favor or against such processes should be preserved in the kinematic history of the Main Uralian fault and in the thermal history of the associated rocks, especially within the high-pressure assemblages of the footwall. If these processes have occurred, younger deformation of Mesozoic and Cenozoic age can be documented as a major factor in the development of the pronounced crustal root and the actual topographic edifice of the Urals.

Exhumation of high pressure and ultra-high pressure terranes in southwestern Uralides.
Ph. Matte, H. Maluski, CNRS Montpellier
V. Puchkov, RAS Ufa

The Urals contain along its entire length one of the best preserved high pressure terrains in mountain belts worldwide. The rocks which suffered a L.T./H.P. metamorphism (blueschists and eclogites) are not affected by late H.T. thermal events. The aim of this project is to carry out detailed structural, petrological and radiometric 39Ar/40Ar studies to determine an accurate age for the high pressure metamorphism as well as the precise age of the uplift, i.e. the PTt path of the high pressure rocks during their exhumation from depths of 50-80 km that has been previously attributed to 380 and 250 Ma.

Fluid induced High-P metamorphism and geodynamics of orogens.
H. Austrheim, Mineralogical-Geological Museum, Oslo
W. Lennykh, Miass

The object of this project is to build a database, from deep crustal rocks exposed in the Urals, Variscides, and Caledonides, over changes in petrophysical properties associated with High-P. metomorphism. These data, which are fundamental for interpretation of geophysical experiments on the deep crust, will also be used to model the geodynamics of crustal root zones. The volume reduction during eclogite formation must affect the geodynamics of orogens possibly by easing subduction or by causing subsidence at the surface.

Petrology and geochemistry of magmatism
F. Bea, Granada University
G. Fershtater, RAS Ekaterinburg

This project is designed to make a systematic study of the geology, petrology, and geochemistry of magmatic plutonic rocks -ophiolites, gabbro-granite complexes, and granitoids- across one wide West-East section in the Urals, in order to obtain primary evidences about the geological evolution of the Urals, to determine how continental crust was generated from oceanic materials, and the metallogenetic speciation and potential of magmatic bodies. Throughout the study of the evolutional trends of ophiolites and granitoids, internal structure of plutons, isotopic analysis and typology of granitoids, the change in composition, age, and emplacement mechanism of magmatic bodies, from the subduction zones to the collision zone, will be computed. Moreover, the Urals give excellent opportunities to investigate the primary composition and structure of ophiolites as well as their transformations in both, subduction and collision zones, the generation of Pt- and Cr-bearing peridotite-gabbro series, which have no equivalent in other parts of the world, and the origin of different types of association of basic and acid magmatic rocks and their role as indicators of geodynamic regimes.

The tectonic framework of mineralization in the Uralides.
H. de Boorder, Utrecht University
Koroteev, Ekaterinburg

The range of mineral deposit types of the Urals is, at first sight, comparable to that of other orogenic belts in Europe. However, apart from those associated with the mafic and ultramafic complexes of oceanic and volcanic island origin, their geodynamic setting is often not as clear as it appear elsewhere in Europe. The later stages of orogenic evolution, recognized in the Variscide and Alpine belts, are not specifically known in the Urals. In addition to processes pertaining to the orogenic regime itself, older structures of the East European Platform may well have had an influence on the occurrence of major ore deposits. For specific surveys are planned: suture zones of the South Urals and their gold mineralization, tectonic nature of the Main Granite Zone (Southeastern Urals mineralizations), tectonic setting of the diamond and gold mineralizations in the Central Urals, and the tectonic setting of the porphyry copper deposits in the Northern Urals.

Geothermal modeling of the lithosphere in the Uralides.
Kukkonen, Espoo,
Golovanova, Ufa

The Uralides are characterized by extremely low heat flow which probably corresponds to depleted radioactive elements in the crust, together with a long relatively narrow linear zone of low outflow of heat from the subcrustal lithosphere. This project includes a review of available temperature logging records from the Uralian boreholes and correlation with the near-surface radiogenic heat production.

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Neotectonics
Chr. Reigber, GFS Potsdam,
Kakevian, Moscow

Horizontal and vertical motions will be observed in a network covering the tectonic features in the southern Urals. The measurements will be performed on the basis of GPS instrumentation. A permanent station will allow repeated measurements. These data, together with geological studies on Neogene basin formation, and active fault systems integrate this investigation.

Stress measurements.
K. Huber, Karlsruhe University
Khakhaev, Jaroslavl

The purpose of this science plan is to document the stress orientations in the central and southern Urals, compare this with data from on-going seismicitiy and interpret the stress field in relation with that of the East European craton and western Europe.

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4) Russian funding for fieldwork (including pilot reflection profile)	Rubles 120,000,000
5) American funding (COCORP)	ECU 165,000

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Appendix A:

Location Map and Table of Acquisition Parameters of Existing Seismic Lines

Kashubin, S.N., Rybalka, V.M., Sokolov, V.B., 1992, pers. comm.

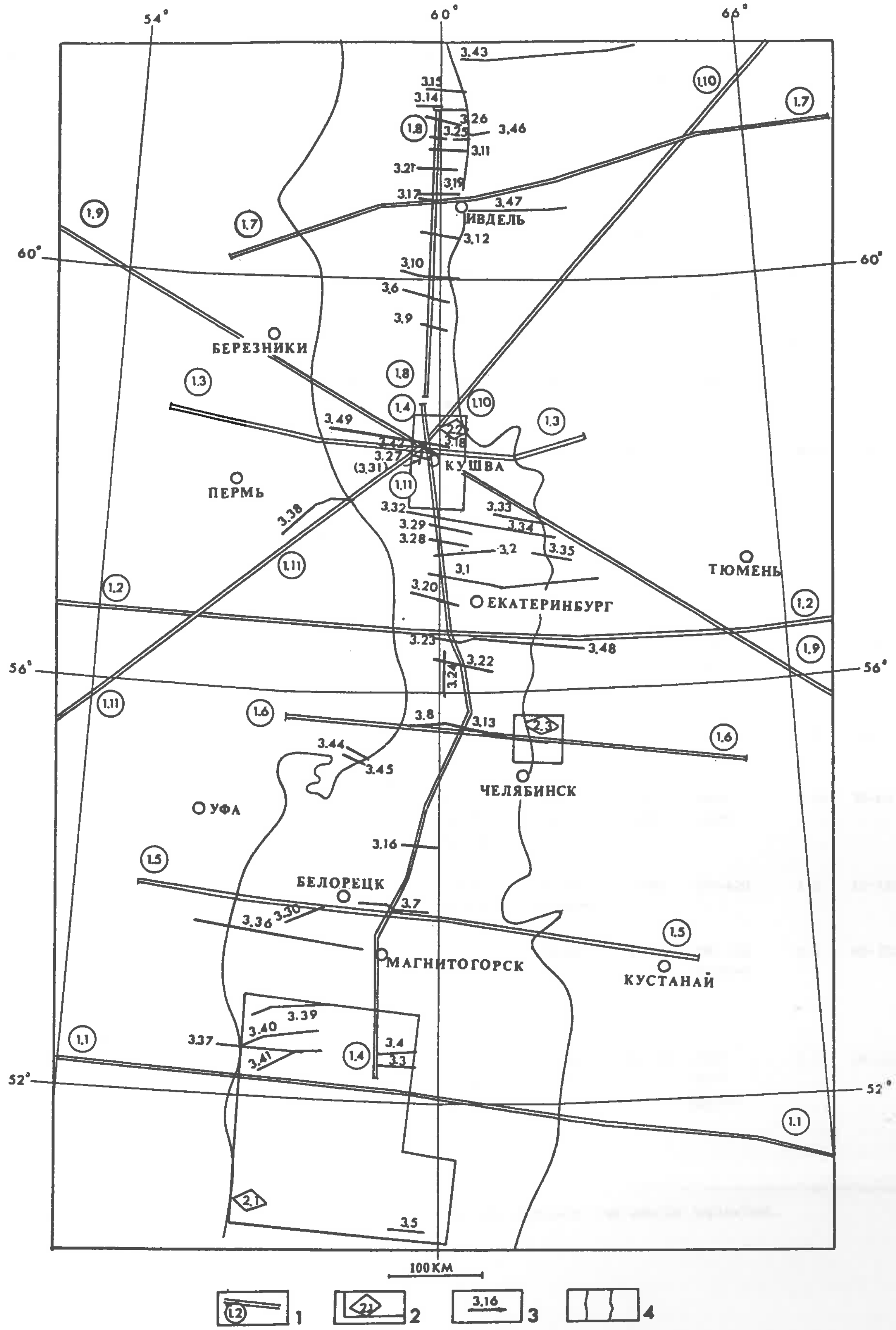

Fig.1. Map of the siesmic profiles.

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Table 1. MAIN INFORMATION ABOUT SEISMIC PROFILES.

N	Profile	Company	Last year of stud.	Length km	Depth km	Equipment: Stations	Equipment: Geophons	Observation parameters: Spacing (Shots) km	Spacing (Receiv.) km	Spacing (Sh.-Rec.) km	Multipl.	Record. length. s	Re
1	2	3	4	5	6	7	8	9	10	11	12	13	
	1. Regional DSS profiles.												
1.1	Temirtau- Kuybyshev	IGE	1969	1400	50	SS-30-60 - KMPV	NSP-3	200* 50**	150- 200 m	400* 100**	2-3	15-20	[38
1.2	Sverdlovsk	BGE	1970	1100	60-70	SS-30-60- KMPV	SPEN-1	100* 30**	100 m	320* 50**	2-3	15-20	[13
1.3	Krasnouralsk	BGE	1980	400	80	Poisk-48- KMPV SMP-48-KMPV Cherepakha	SV-5 SV-110 NSP-3	20* 10**	20* 10**	380* 80**	8-12	24	[18
1.4	N.Tura-Orsk	BGE	1983	800	70-80	Poisk-48- KMPV SMP-48-KMPV	SV-5 SV-10	20* 10**	20* 10**	450* 80*	8-14	24	[9]
1.5.	Troitsk	BGE	1986	600	70-80	Poisk-48- KMPV SMP-48-KMPV Progress-2	SV-5 SV-10 SKZ-10-Ts	20* 10**	20* 10**	360* 80**	8-14	24-60	[1]
1.6.	Taratash	BGE	1988	500	70-80	Progress-2	SV-5 SV-10 SKZ-10-Ts	20* 10**	20* 10**	360* 80**	8-14	30-60	[15
1.7	Krasnoleninsk	BGE	1988	670	50-60	Taiga-2	SV-5	36* 12**	3-10	200* 80**	6-8	60	-
1.8.	N.Tura-Vizhay	BGE	1989	300	70-80	Progress-2	SV-5 SV-10 SKZ-10-Ts	20* 10**	20* 10**	360* 80**	8-14	30-60	-
1.9.	Kostomuksha-	TsRGiGI "GEON"	1990	2900	100-110	Taiga-2 Cherepakha	NSP-3 SK-1-P	50-80 2200***	7-10	150-420	4-8	60-120	-
1.10	N.Tagil-Urengoi (eastern part of geotravers "Granit"	TsRGiGI "GEON"	1990	1500	100-110	Taiga-2 Cherepakha	NSP-3 SK-1-P	50-80	7-10	150-420 1600***	4-8	60-120	-
1.11.	Urengoy-N.Tura- Krivoy Rog (central part of geotravers "Granit"	BGE	not accompl.	1800	100-110	Progress-2 Cherepakha Taiga-2	SV-5 SV-10 SK-1-P	30-45 * 15**	5-7.5	375* 75** 1600***	5-11	30-600	[7

Notes: * - DSS system; ** - reflection and refraction systems; *** - maximal distances from special explosions.

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Table 1 (Continuation 1).

N	Profile	Company	Last year of stud.	Length km	Depth km	Equipment: Stations	Equipment: Geophons	Observation parameters: Spac. (Shots) km	Spac. (Receiv.) km	Spac. (Sh.-Rec.) km	Multipl.	Record length s	Ref
1	2	3	4	5	6	7	8	9	10	11	12	13	
	2. Regional areal studies.												
2.1.	Areal studies with industr. explosions	IG UrO RAN	1975	50000 sq.km *	50	Zemlya PSL-3,SS-24P APMZ-ChM	SPEN-1 SPM-16	15-120	3-30	up to 250	1-3	30-60	[41]
2.2	Krasnouralsk area	BGE	1980	5500 sq.km	60	SMP-48-KMPV Poisk-48-KMPV Cherepakha	SV-5 SV-10 NSP-3	15-30	7-8	up to 200	3-8	24	[18]
2.3.	Muslyumovsk area	BGE	1988	2500 sq.km	8** 70***	Progress-2	SV-5 SV-10 SKZ-10-Ts	10	10	60	4-8 25****	30	[12,43]

Notes: * - total area studied from 1960 up to 1975; ** - refraction method; *** - reflection method;
**** - multiplication at line crosspoints in the centre of the area

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Table 1 (Continuation 2).

N	Profile	Company	Last year of stud.	Length km	Depth km	Equipment Stations	Geophons	Observation parameters Spac. (Shots). km	Spac. (Receiv.). km	Spac. (Sh.-Rec.). km	Multipl.	Record length s	Ref
1	2	3	4	5	6	7	8	9	10	11	12	13	
						3. Reflection profiles.							
3.1.	Asbestovsk	BGE	1970	214	20-30	SS-30-60-KMPV Poisk-48-MOV	SPEN-1	9,000	50	18,000	2	12	[19]
3.2	Kirovograd	BGE	1972	75	8-10	Poisk-48-MOV	SVM-30	690	30	1,380	2	5	[26,3
3.3	Bogdanov	BGE	1972	60	8-10	Poisk-48-MOV	SVM-30	1,150	50	2,300	2	6	[6]
3.4.	Chekinsk	BGE	1973	50	8-10	Poisk-48-MOV	SVM-30	1,150	50	2,300	2	6	[6]
3.5	Maldygulsay	BGE	1973	25	6	Poisk-48-MOV	SVM-30	690	30	1,380	2	6	-
3.6	Volchansk	BGE	1974	80	5	SM-48	SVM-30	575	25	1,150	2	5	[21]
3.7	Verchneuralsk	BGE	1974	139	12	Poisk-48-MOV	SVM-30	1,150	50	2,300	2	6	[14]
3.8	Taratash	BGE	1975	92	12	Poisk-48-MOV	SVM-30	575	25	1,150	2	10	[22]
3.9	Totinsk	BGE	1975	42	5-6	SM-48	SVM-30	575	25	1,150	2	5	-
3.10	Maslovsk	BGE	1976	58	7-9	SM-48	S-130	575	25	1,150	2	5	[140]
3.11	Vizhay	BGE	1977	61	10	SM-48	S-130	575	25	1,150	2	5	[40]
3.12	Vsevolodo-Blagodatsk	BGE	1977	40	10	SMOV-24	S-130	575	25	1,150	2	5	[42]
3.13	Techensk	BGE	1977	50	10-12	Poisk-48-MOV	SVM-30	575	25	1,150	2	5	-
3.14	Sos'vinsk	BGE	1978	55	5-7	Poisk-48-MOV	SVM-30	575	25	1,150	2	5	[36]
3.15	Ust'Man'insk	BGE	1978	60	5-7	Poisk-48-MOV	SVM-30	575	25	1,150	2	5	[37]
3.16	Vydrinsk	BGE	1979	30	8	Poisk-48-MOV	SVM-30	1,150	50	2,300	2	6	[39]
3.17	Parminsk	BGE	1979	70	9	SMOV-24	S-130	575	25	1,150	2	6	-
3.18	V. Tura	BGE	1979	68	10	SMOV-24	SV-20	575	25	1,150	2	6	[32]
3.19	Sukchodoy	BGE	1980	75	5-7	SMOV-24	S-130	575	25	1,150	2	6	-
3.20	Kormovischensk	BGE	1981	56	10	SMOV-24	SV-20	575	25	1,150	2	6	[28]
3.21	Burmantovsk II	BGE	1981	50	9	SMOV-24	S-130	575	25	1,150	2	4	-
3.22	Svetlorechensk-Sysert'	BGE	1981	67	10	SMOV-24	SV-20	575	25	1,150	2	6	[16]
3.23	Degtyarsk	BGE	1982	37	10-12	SMOV-24	SV-20	575	25	1,150	2	6	[33]
3.24	Polevsk	BGE	1982	29	10	SMOV-24	SV-20	575	25	1,150	2	6	[29]
3.25	Kotliysk	BGE	1982	35	9	SMOV-24	S-130	575	25	1,150	2	5	-

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3.26 V.Loz'vinsk	BGE	1983	58	9	SMOV-24	S-130	575	25	1,150	2	5	[20]
3.27 Meridional (SG-4)	BGE	1983	28	16	Progress-2	SV-20	1,150-2,300	25-50	1,150-9,200	2-4	5-10	[5]
Latitudinal (SG-4)			26									
3.28 Shaytansk	BGE	1984	31	15	Progress-2	SV-20	575	25	1,150	2	6	[34]
			13**				1,150**	1(9)**				
3.29 Levikhinsk	BGE	1984	44	20	Progress-2	SV-20	575	25	1,150	2	6	[31]
3.30 Zigaza-Sermenevo	"Bashkir-geologiya"	1984	80	8	Progress-2	SV-20	575	25	1,150	2	5	-
3.31 Meridional (SG-4)	BGE	1985	28	26	Progress-2	SV-5	2,300	2,300	up to 22,000	7-8	15	-
Latitudinal			26			SV-10		1,100*1,100				
(SG-4)			7**			SV-20**	1,150**	1(13)**	1,150**	1(13)**	6**	
3.32 Chernoisto-chinsk-Alapaevo	BGE	1986	127	22	Progress-2	SV-20	600	25	1,200	2	8	[3]
			24**				1,200**	50**	1,200**	1(9)**		
3.33 Koptelovsk	BGE	1987	55	5-7	Progress-2	SV-20	600	25	1,200	2	8	-
3.34 Aramashevsk	BGE	1987	38	5-7	Progress-2	SV-20	600	25	1,200	2	8	-
3.35 Mostovsk	BGE	1987	39	5-7	Progress-2	SV-20	600	25	1,200	2	8	-
3.36 Profile 06	"Bashnef-tegeofizika"	1987	203	15-20	Progress-2	SV-20	100	100	2,450	24	7-12	[27]
3.37 Profile 04	"Bashnef-tegeofizika"	1988	172	10-15	Progress-3	SV-20	100	100	2,450	24	6	-
3.38 Profile 01	"Perm'nef-tegeofizika"	1989	87	5	Progress-3	SV-20	50	50	3,150	48	4	-
3.39 Profile 114	"Bashkir-geologiya"	1989	97	10-15	Progress-3	SV-20	100	100	2,450	24	6	-
3.40 Profile 115	"Bashkir-geologiya"	1989	88	10-15	Progress-3	SV-20	100	100	2,450	24	6	-
3.41 Profile 116	"Bashkir-geologiya"	1989	95	10-15	Progress-3	SV-20	100	100	2,450	24	6	-
3.42 CDP Profile (SG-4)	KamNIIKIGS	1989	15	16	Progress-2	SV-20	100	50	1,150	12	5	-
3.43 Profile XIII	BGE	1989	194	8	Progress-2	SV-20	100	50	1,200	12	6	-
3.44 Alexandrov	BGE	1991	20	5	Progress-3	SV-20	600	25	1,200	2	5	[24]
			8				100	25	600	6		
3.45 Aylinsk	BGE	1991	31	5	Progress-3	SV-20	600	25	1,200	2	5	[24]
			8				100	25	600	6		
3.46 Kotliysk	BGE	1992	25	8	Progress-96	SV-20	100	50	2,400	24	5	-
3.47 Profile R-2	BGE	not accompl.	110	8	Progress-96	SV-20	100	50	2,400	24	4	-
3.48 Sosnovsk	BGE	not accompl.	75	22	Progress-2	SV-20	600	25	1,200	2	8	-

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3.49 Saranovsk	BGE	not accompl.	47	12	Progress-2	SV-20	600	25	1,200	2	5	-

Notes: * - distance, m; ** - common shot gather observations.

[38] - Khrychev et al, 1983; [13] - Druzhinin et al, 1976; [18] - Druzhinin et al., 1981; [9] - Druzhinin et al., 1985;
[1] - Avtoneev et al., 1988; [15] - Druzhinin et al, 1990,a, [7] - Geotravers "Granit", 1992; [41] - Khalevin, 1975;
[12] - Druzhinin et al., 1990,c; [43] - Kashubin, 1991; [19] - Sokolov et al., 1974; [26] - Sokolov et al., 1974; [35] - Sokolov e
Menshikov et al., 1978; [21] - Segal et al, 1975, [14] - Menshikov, 1980; [22] - Pankov et al. 1979; [40] - Kazachikhin et al., 19
et al., 1981; [36] - Sokolov and Nazarov, 1980; [37] - Sokolov and Nazarov, 1981; [39] - lenshikov et al., 1983; [32] - Sokolov et
Sokolov, 1985; [16] - Sokolov, 1988; [33] - Sokolov et al., 1984; [29] - Sokolov, 1987; [20] - Segal et al., 1985; [5] - Druzhinin
Bliznetsov, 1987; [34] - Sokolov and Zenkov, 1988; [31] - Sokolov and Averkin, 1988; [3] - Bliznetsov, 1988; [27] - Skripiy and Yu
Popov et al., 1991.

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Appendix B:

Data Compilation, 11 Maps of the Urals

Rybalka, V.M., Ananyeva, E.M., Kashubin, S.N., Semenov, B.G., Ryzhiy, B.P., Druzhinin, V.S., Khachay, Yu.V., 1992, pers. comm.

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Krasnouralsk area	60	15-30	7-8	up to 200	3-8	4
Muslyumovskaya area	8* 70**	10	10	60	4-8 25***	6

Notes: * - refraction shooting; ** - reflection shooting; *** - multiplication at the profiles crosspoint in the centre of the area.

3. Reflection profiles.

1	2	3*	4*	5*	6	7
More than 40 2-fold reflect. profiles, total length 2500 km	5-10	575-1150	25-50	1150-2300	2	11,15, 16
CDP profiles approaching the Urals from platform areas	5-15	50-100	50-100	2450-3150	12-48	14

Notes: * - distances in m.

References: 1 - Avtoneev et al., 1988; 3 - Druzhinin et al., 1976; 4 - Druzhinin et al., 1981; 5 - Druzhinin et al., 1990,a; 6 - Druzhinin et al, 1990,b; 7 - Khalevin, 1975; 9 - Khrychev et al., 1968; 11 - Segal et al., 1985; 14 - Skrypiy and Yunusov, 1989, 15 - Sokolov et al., 1974; 16 - Sokolov and Averkin, 1988.

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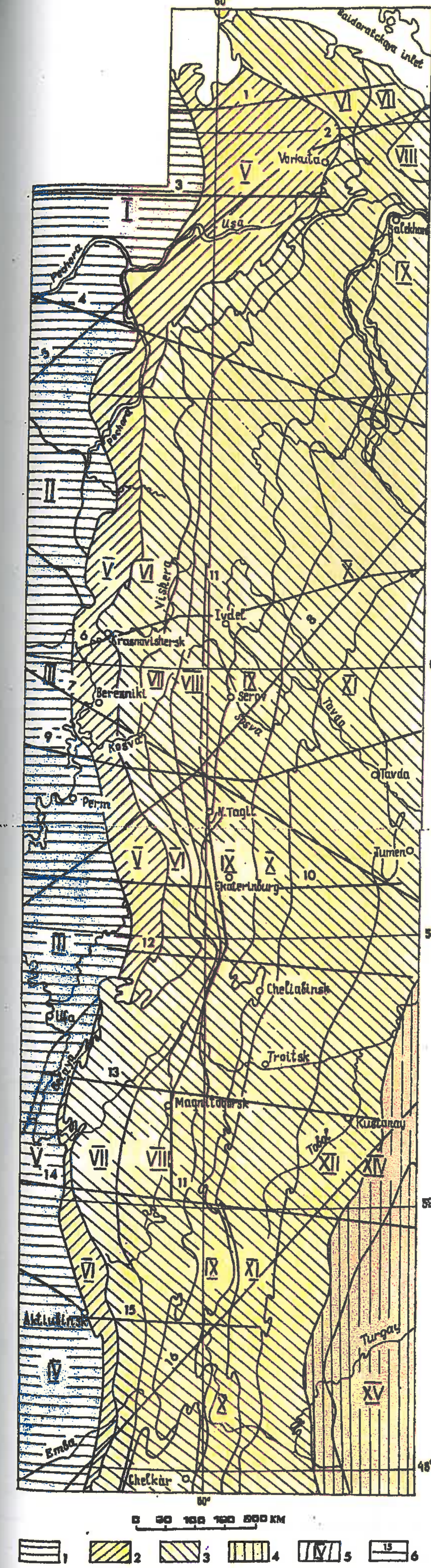


Fig.1 Map of tectonic areas and DSS profiles in the Urals.

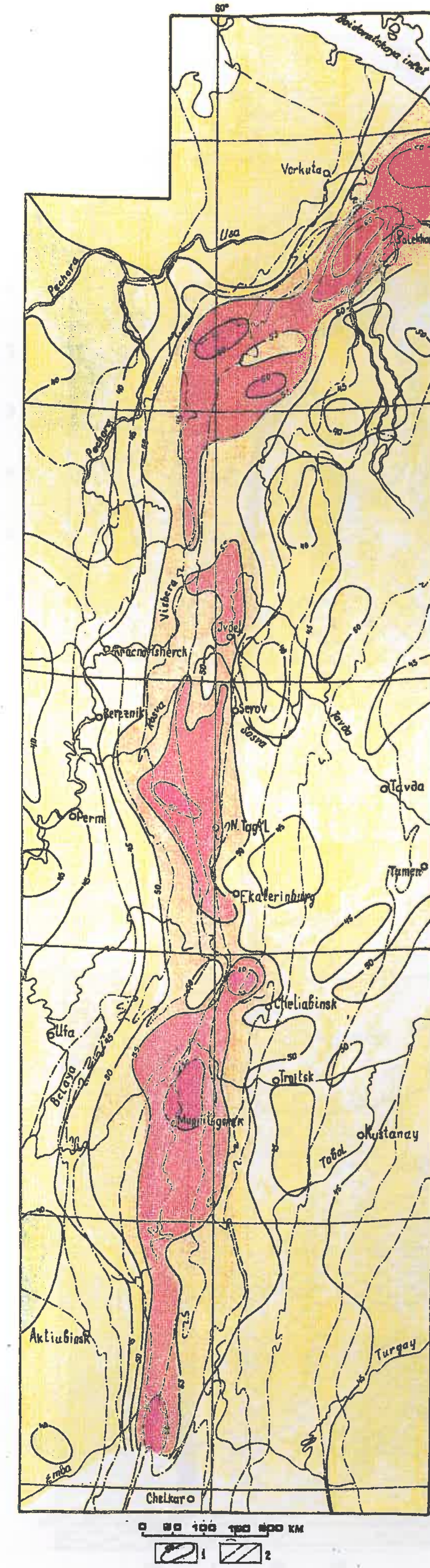
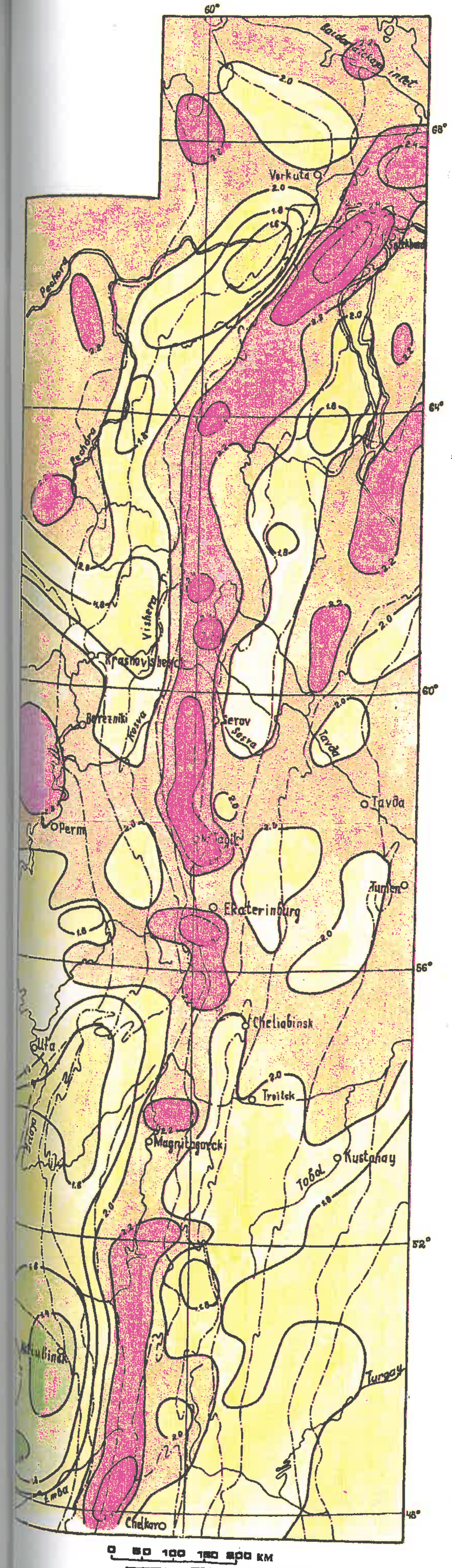


Fig.2 Map of the Earth crust thickness of the Urals.



.3 Map of the Earth crust "mafisity" of the Urals.

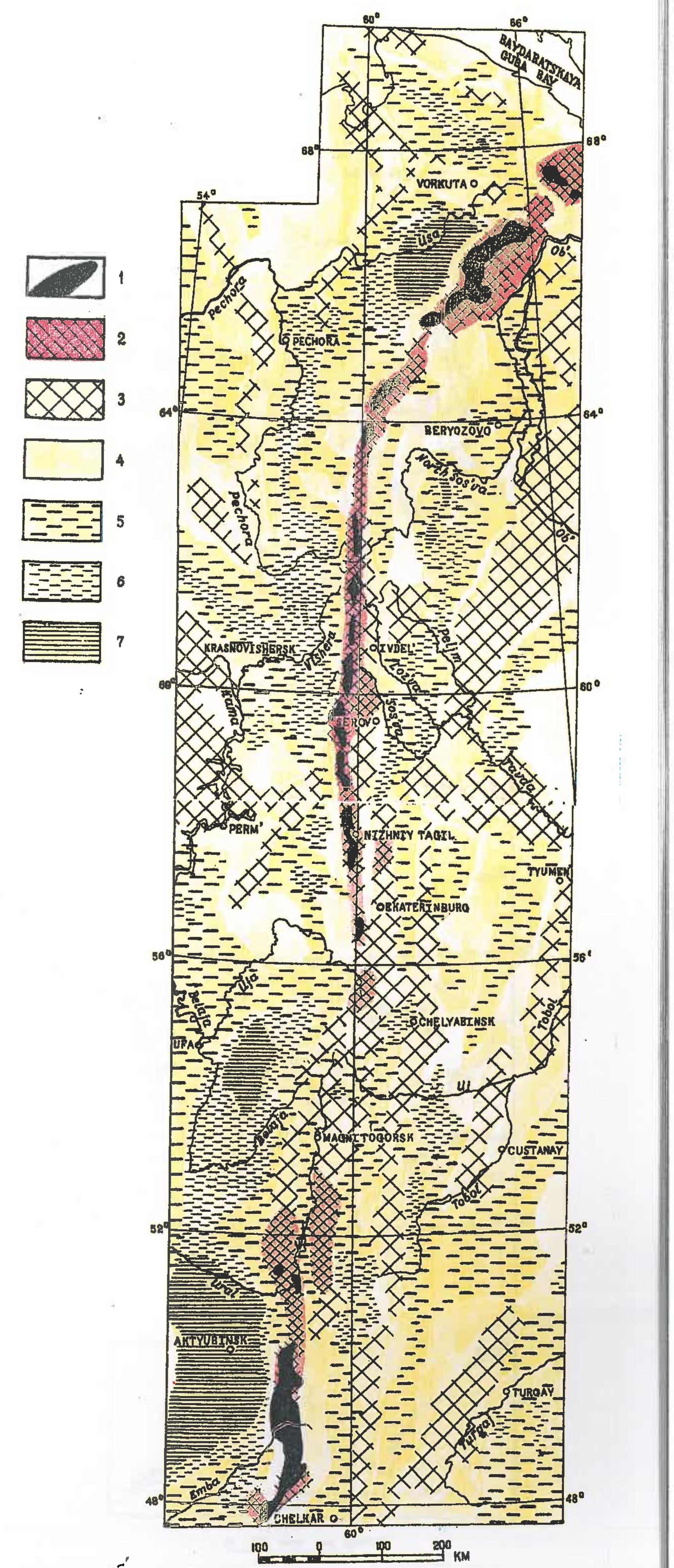


Fig.4 Distribution of the Ural's gravity anomalies.

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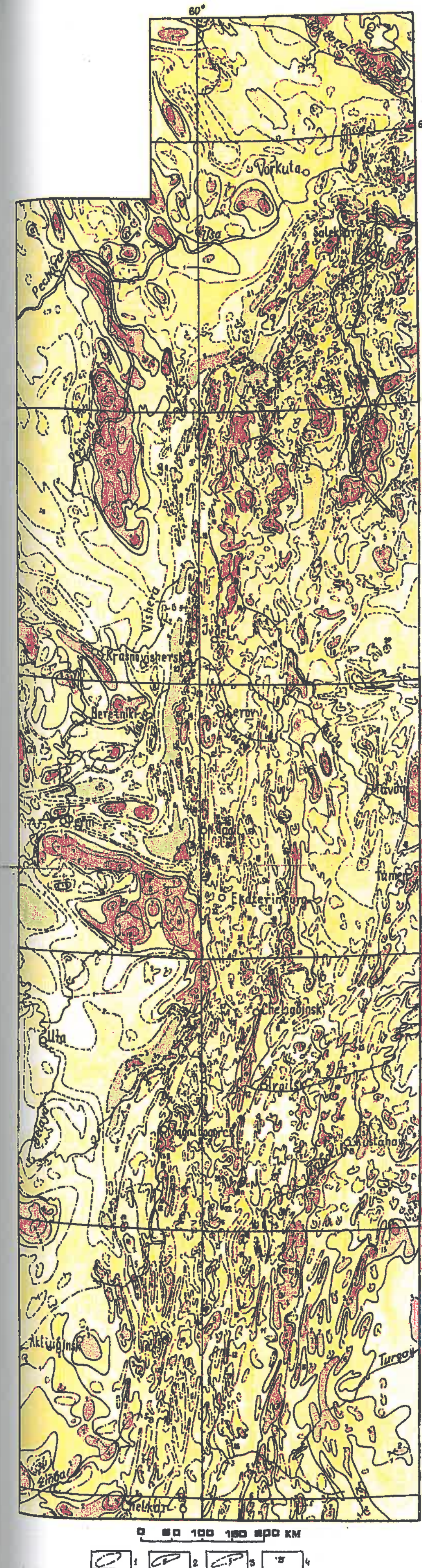

Fig.5 Map of magnetic anomalies of total intensity.

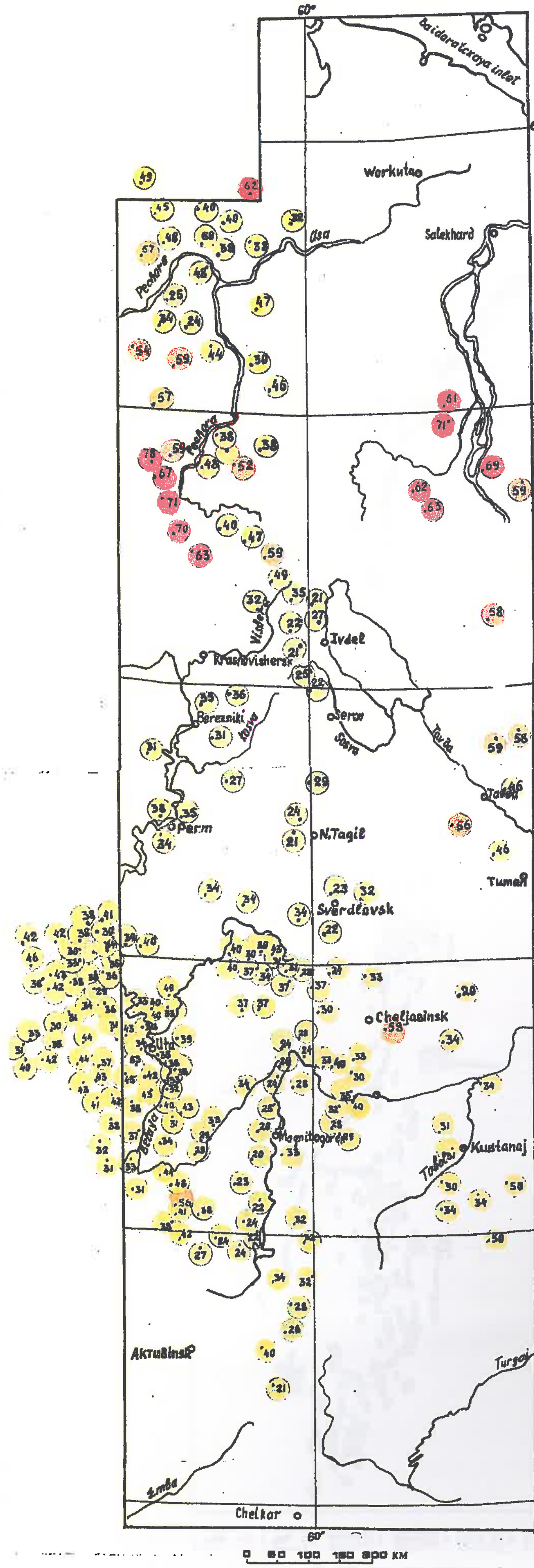

Fig.6 Heat flow map of the Urals.

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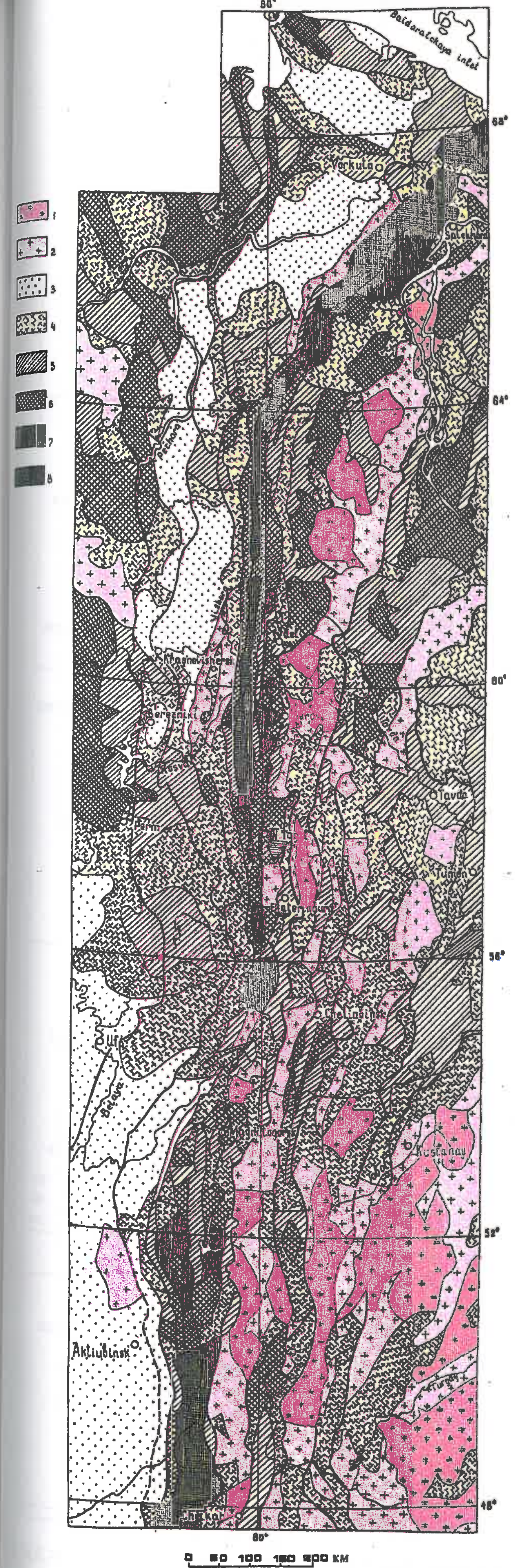

Fig.7 Map of the upper crust blocks.

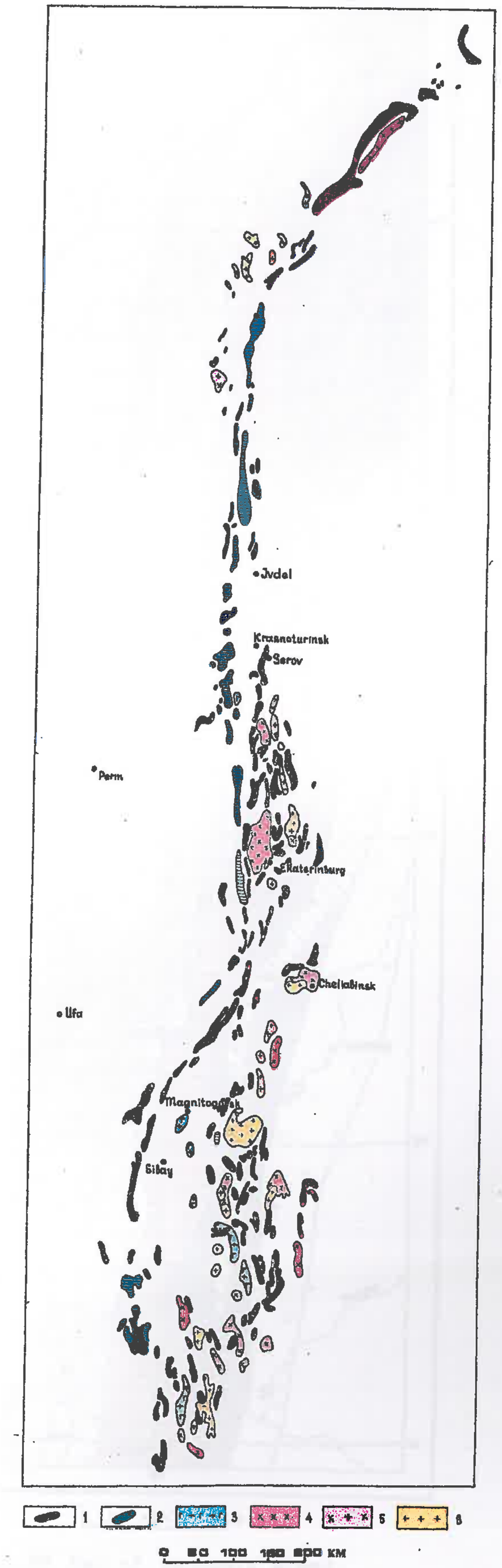

Fig.8 Scheme of intrusive massifs of the Urals.

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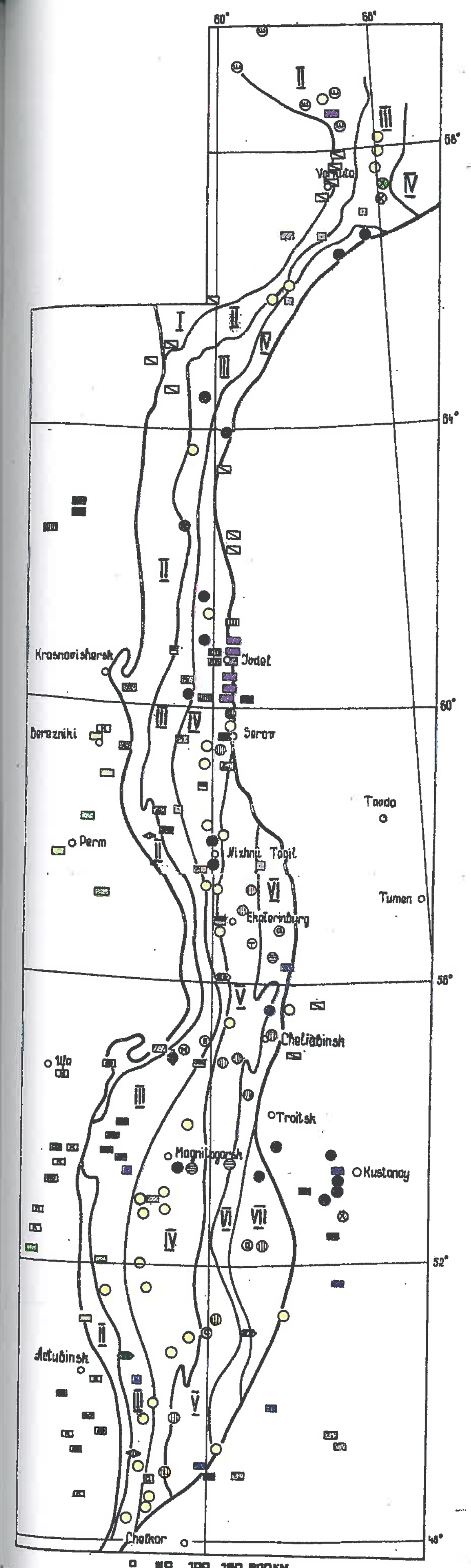

MINERAL RESOURCES MAP OF THE URALS

Fig. 9 The legend

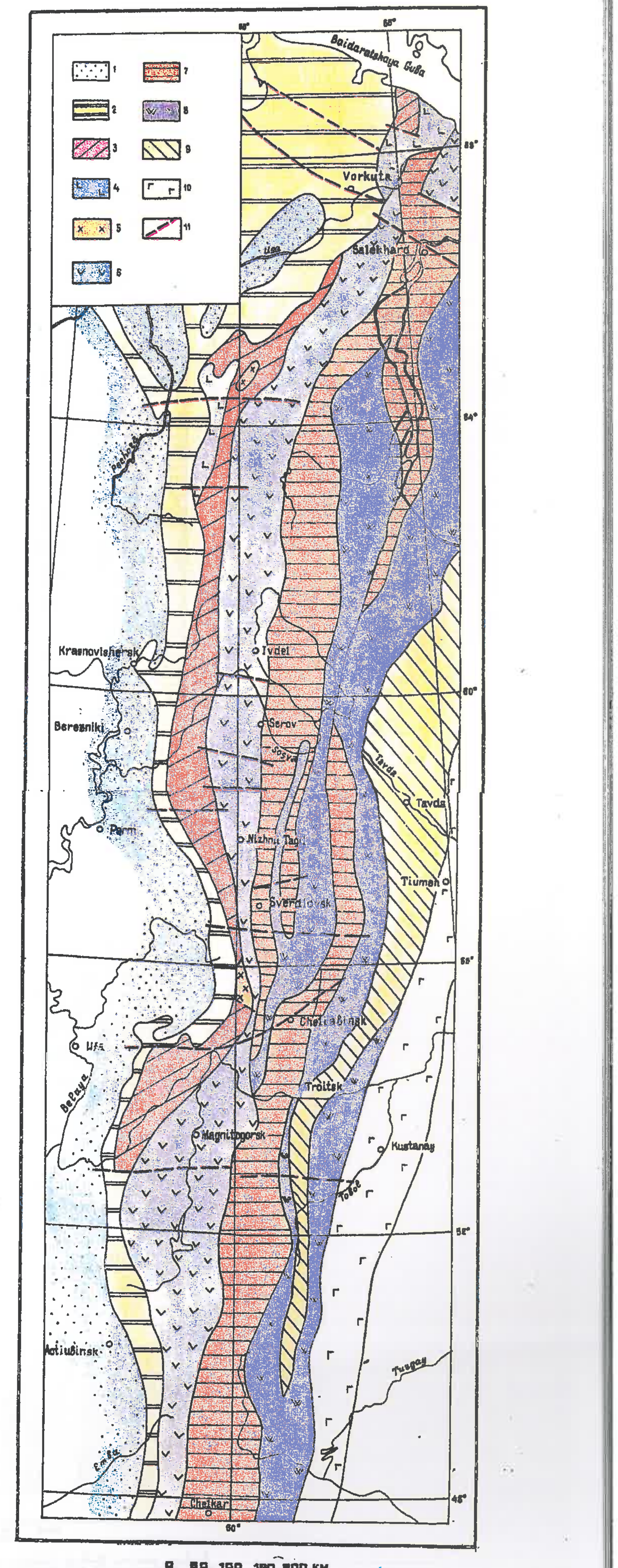

Fig.10 Map of tectonic areas.

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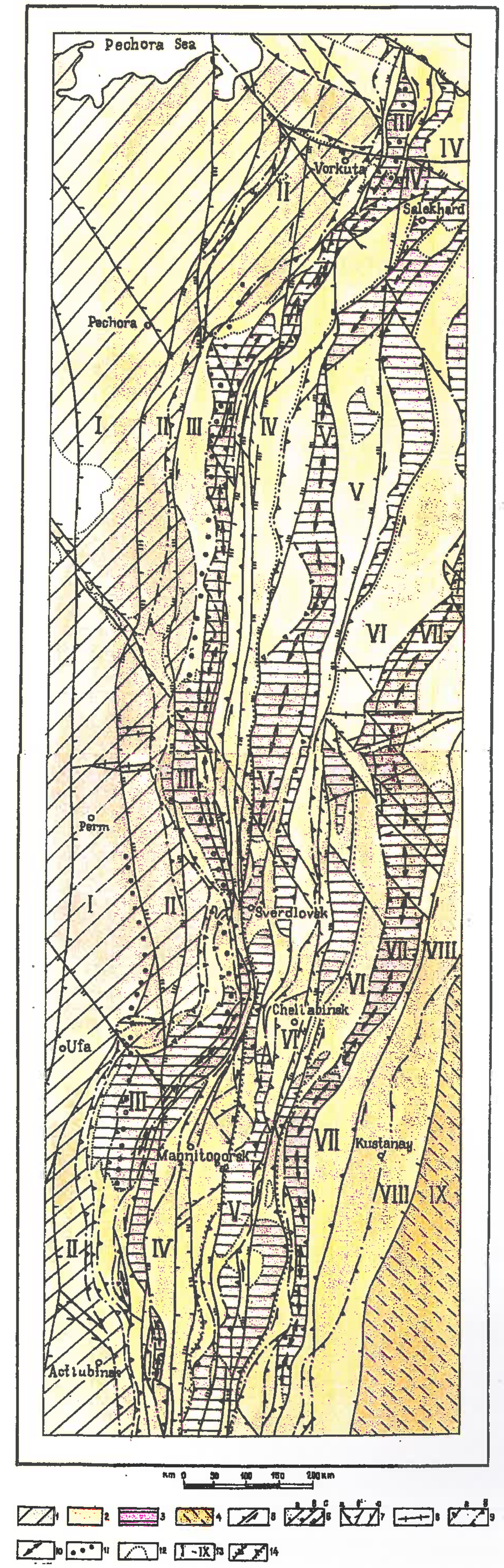

Fig.11 Scheme of Mesozoic and Kainozoic tectonics.

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Appendix C:

Data Compilation, Middle and Southern Transects of theUrals

UralGeolCom, 1992

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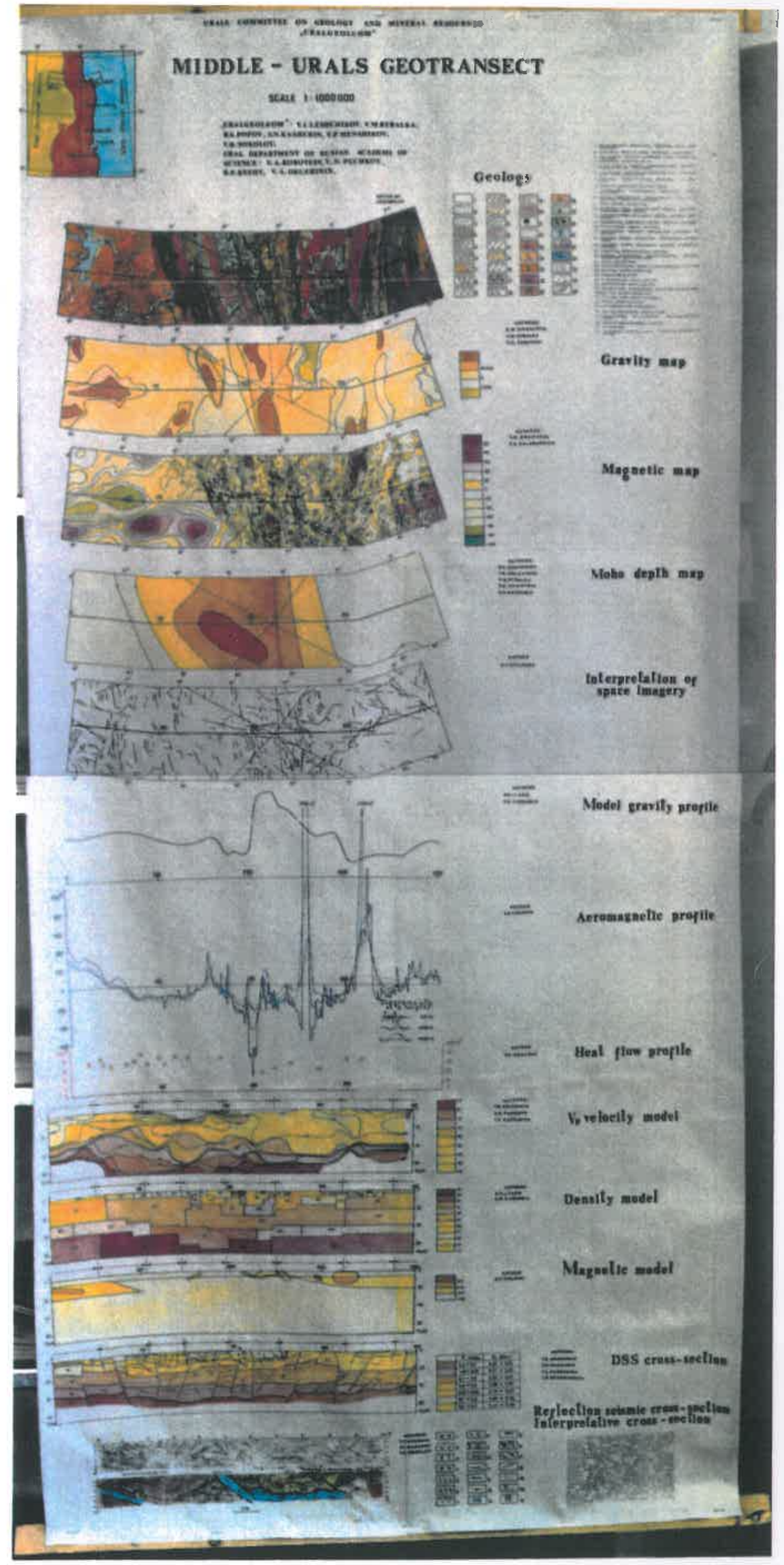

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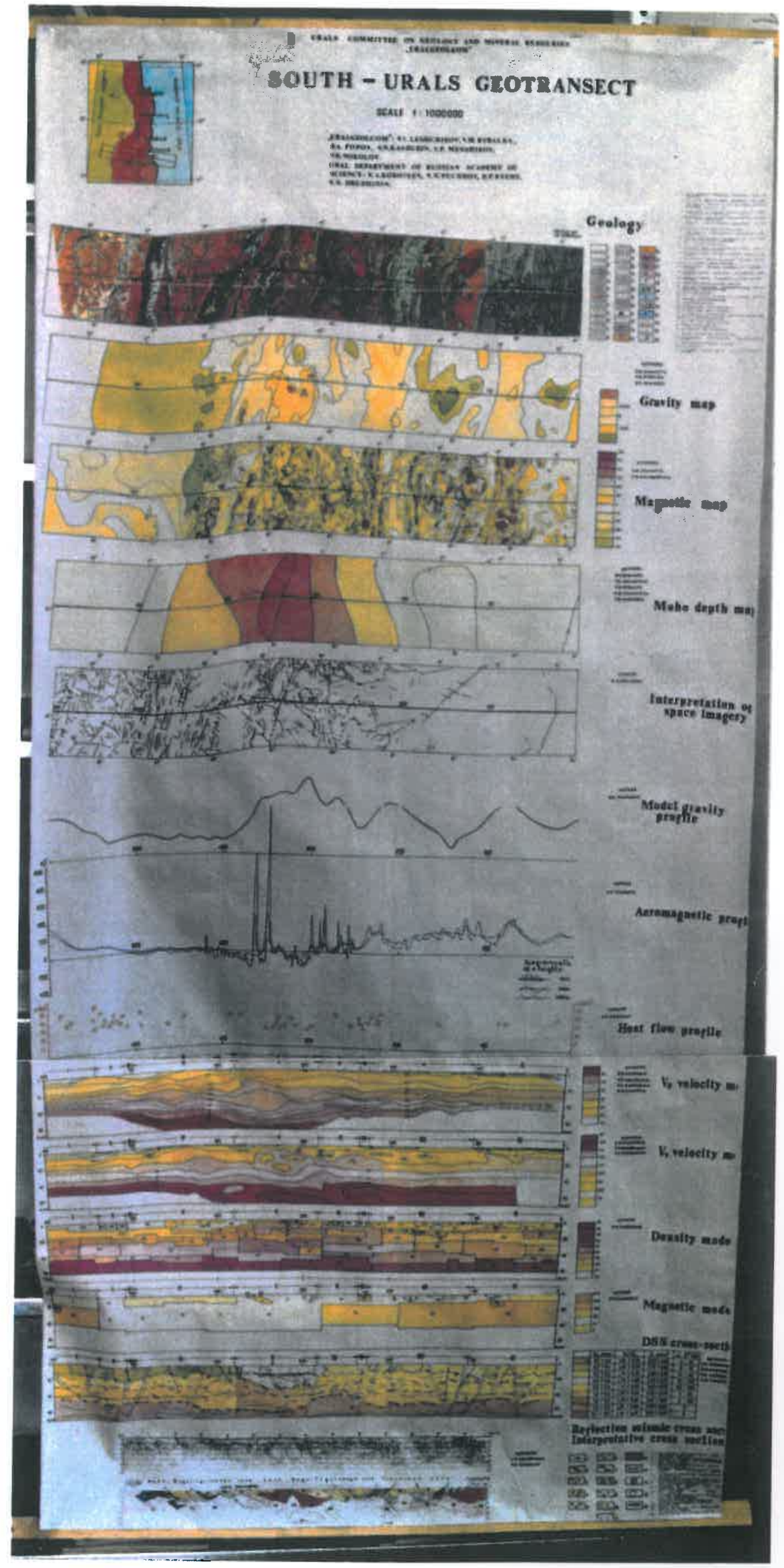

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Appendix D:

List of Proposed Field Parameters and Expenditures

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Outline
of Field Configuration and Parameters
for **one** 500 km CMP-Reflection Profile in the URALS

General Parameters:

	near-vertical	wide-angle
Length of Profile	500 km	500 km
Spacing of Shotpoints	200 m	20 km
Number of Shotpoints	2.500	25 (repeated 10 x)
Size of Explosives / Shotpoint	30 - 50 kg	200-500 kg
Sum of Explosives	75 - 125 t	50-125 t
Number of Recording Channels	400 (min.)	400 (10 move-up)
Spacing of Receiver	50 m	50 m
Length of Spread	20 km (min.)	200 km
CMP Coverage	50	5
Configuration	split spread 10-10 km	0-200 km
Record Length	30 s	90 s

Drilling:

	near-vertical	wide-angle
Number of Drilling Rig (inc. Crew)	10	4
Number of Drillholes per Crew per Day	3	3
Drillholes total per Day	30	12
Duration of Drilling Operation	83 days (14 weeks)	21 (3-4 weeks)

Recording:

	near-vertical	wide-angle
Number of Shots per Day	50	5
Rollalong per Day	10 km (200 groups)	
Duration of Acquisition	50 days (500h, 9 weeks)	

Expenditures:

Recording	1	400ch telemetry system in 4-wheel truck,
	2	large trucks for transportation of cable and geophones (Mob/Demob only)
	600	Geophonestrings (of 24 geophones each)
	600	Cables
	600	Station-Units (telemetry boxes) or equivalent for 600 channels

1	Party Chief
2	Operators
2	Driver/Helper
1	Radio-Link shot-receiver (incl. relais for larger distances) plus shooting equipment
2	Service-Man

Drilling:

10 Drilling Crews (near-vertical) plus
4 Drilling Crews (wide-angle)

each with:

1 heavy or medium Drilling Rig
1 water truck
1 supply vehicle
4 drillers (min.)

75 t Explosives for standard profiling
plus 50-125 t Explosives for additional wide-angle record.

3 holes per day with
30 m depth (average)

Line-Moveup:

6 crews

each with

1 truck
5 persons

moving 10 km line per day:
200 geophone groups

Line-Check:

2 crews

each with

1 vehicle
2 persons

Surveying, permit, static corrections, Fuel+Food Logistics.

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