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A TECTONIC RECONSTRUCTION
OF THE URAL MOUNTAINS, U.S.S.R.

presented by

Jay Brian Silber

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M.S. degree in Geology

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A TECTONIC RECONSTRUCTION OF THE URAL MOUNTAINS, U.S.S.R.

by

Jay Brian Silber

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ABSTRACT

A TECTONIC RECONSTRUCTION OF THE URAL MOUNTAINS, U.S.S.R.

By

Jay Brian Silber

The southern Urals, central USSR, can be subdivided into nine elongate north-south striking terranes. From west to east these are the Ufa-Bashkir, Zilair, Uraltau, Sakmara, Magnitogorsk, Bredy, East Ural, Turgay, and Ishim terranes. The first three and the East Ural terrane are composed of continental crust while the remainder are oceanic in origin. The Sakmara, Magnitogorsk, and Turgay terranes also preserve evidence of former island arcs.

The Ural Mountains were created as a result of obduction of these arcs and intervening back-arc crust onto the Russian Platform between the Early Devonian and the Middle Carboniferous. The evolution of the Urals can be explained solely by westward dipping subduction zones and without complete closure between the Russian Platform and the Kazakhstanian plate.

This work is dedicated to Harold and Rhea Silber.

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The friendship and intellect of Wayne Schroll have been invaluable over the course of the past two years.

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INTRODUCTION

Tectonic reconstructions throughout the world provide important academic information to scientists and industry. The Ural Mountains have been a major source of economic mineral deposits and consequently have received much attention from Soviet geologists and geophysicists. Little work, however, has been done by researchers outside the Soviet Union along the lines of a complete plate tectonic reconstruction of the Urals: the interaction of the Baltican (Russian), Siberian, and Kazakhstanian plates and the implications of such interactions. Soviet tectonic reconstructions use the concepts of vertical tectonics which does not require the entire region to be treated as a whole, but rather suffices to explain each structure as an independent unit with minimal influence imposed by surrounding structures. Information gleaned from geologic maps and translated Soviet literature can be interpreted to create a model where the basic premise is within the realm of currently accepted geologic and tectonic processes, i.e., the new global tectonics.

The primary objective of this study is to develop a plate tectonic model for the origin and evolution of the Uralian region. In the process, a regional geologic summary is developed and paleomagnetic data are summarized. A short digression into the Soviet geologic philosophy is included in order to better understand their classification of features and tectonic interpretation. It is not the intent of this research to study the Urals in great detail with respect to every field in the geological sciences, but rather to create a working model for future researchers to use as a guide for more detailed studies in their chosen specialties or in more restricted regions. Although this study is based on available Soviet data, the data are approached and interpreted in a context not usually accepted by Soviet geologists. First, a data base is collected and discussed, then the Southern Urals are divided into tectonostratigraphic terranes in a manner similar to Jones and Silberling (1980). Each terrane is then interpreted in terms of depositional environments consistent with the new global tectonics. Divisions of the Urals used by Soviet researchers have been retained in several instances, however, additional terranes have also been defined. Using the information presented, a model is then described, followed by a discussion of the viability and advantages of the proposed plate tectonic model.

The Ural Mountains are located in the Soviet Union between longitude 55° - 66° E and latitude 48° - 77° N (Figure 1). This complex orogenic zone ranges from Novaya Zemlya in the north to the region of the Caspian and Aral seas in the south. The southern terminus of the Urals is

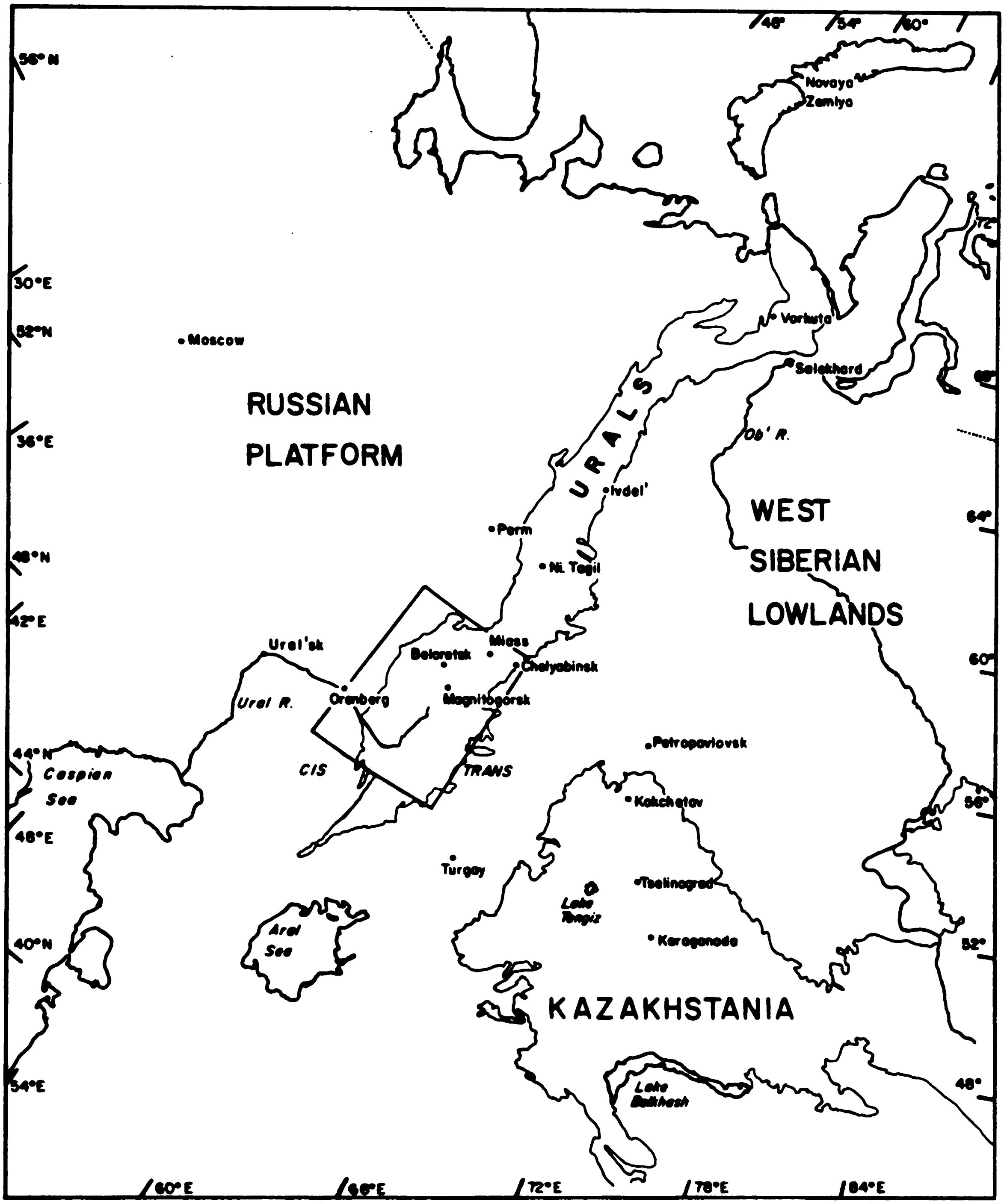
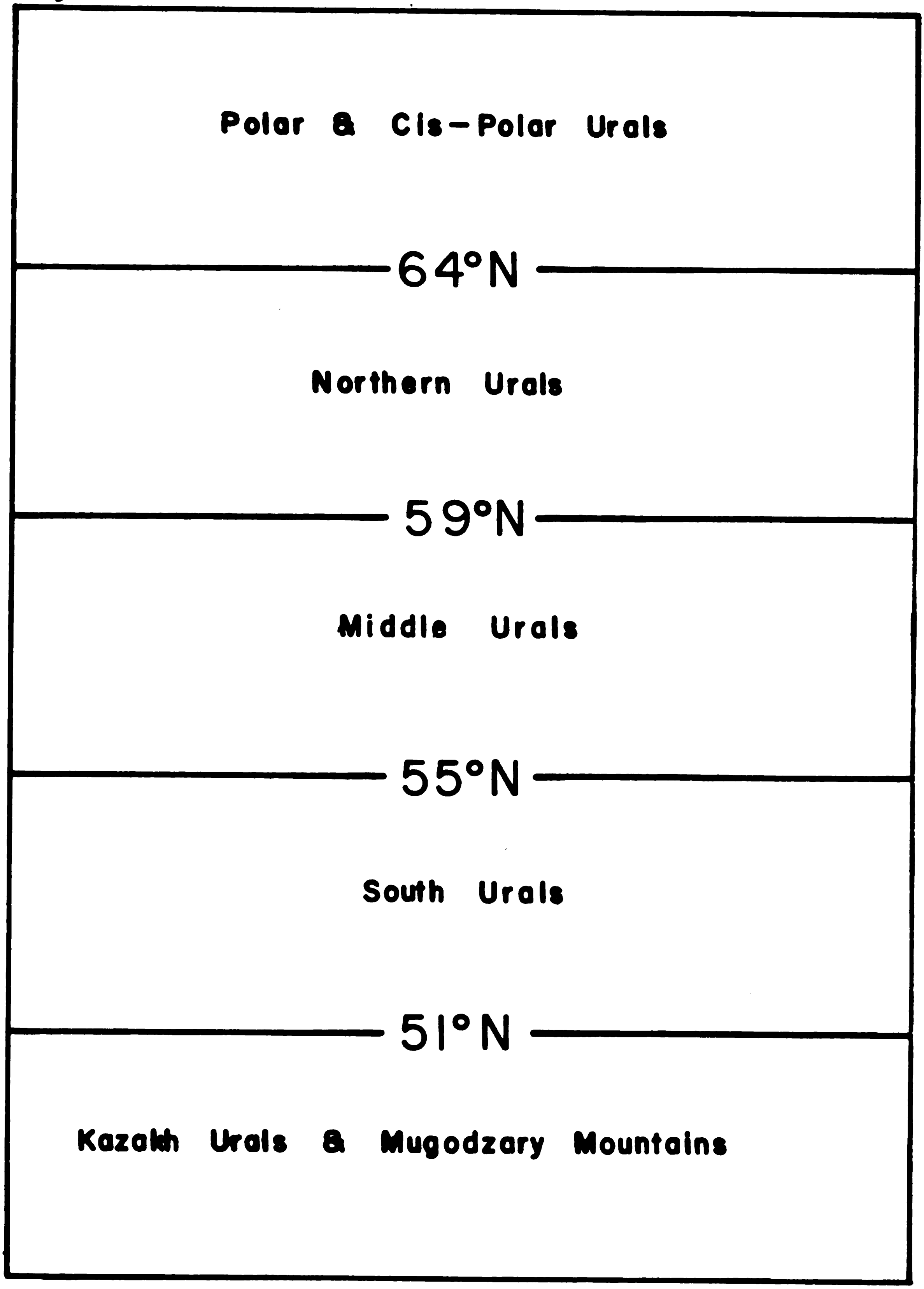


Figure 1. Location of study area. Outlines of major regions are shown. Box outline marks location of Figure 3. Dotted line is Arctic Circle.

Figure 2. Subdivision of the Ural Mountains (according to Ivanov et al., 1975).

Figure 2.


Polar & Cis-Polar Urals
64°N
Northern Urals
59°N
Middle Urals
55°N
South Urals
51°N
Kazakh Urals & Mugodzary Mountains

buried under Cenozoic age sediments. The Ural Mountains are divided into five segments, the Polar, North, Middle, South, and Kazakh Urals (Figure 2) by the Russians. This study concentrates primarily on the Southern Urals and adjacent portions of Kazakhstania and the Russian and Siberian platforms (Figure 1).

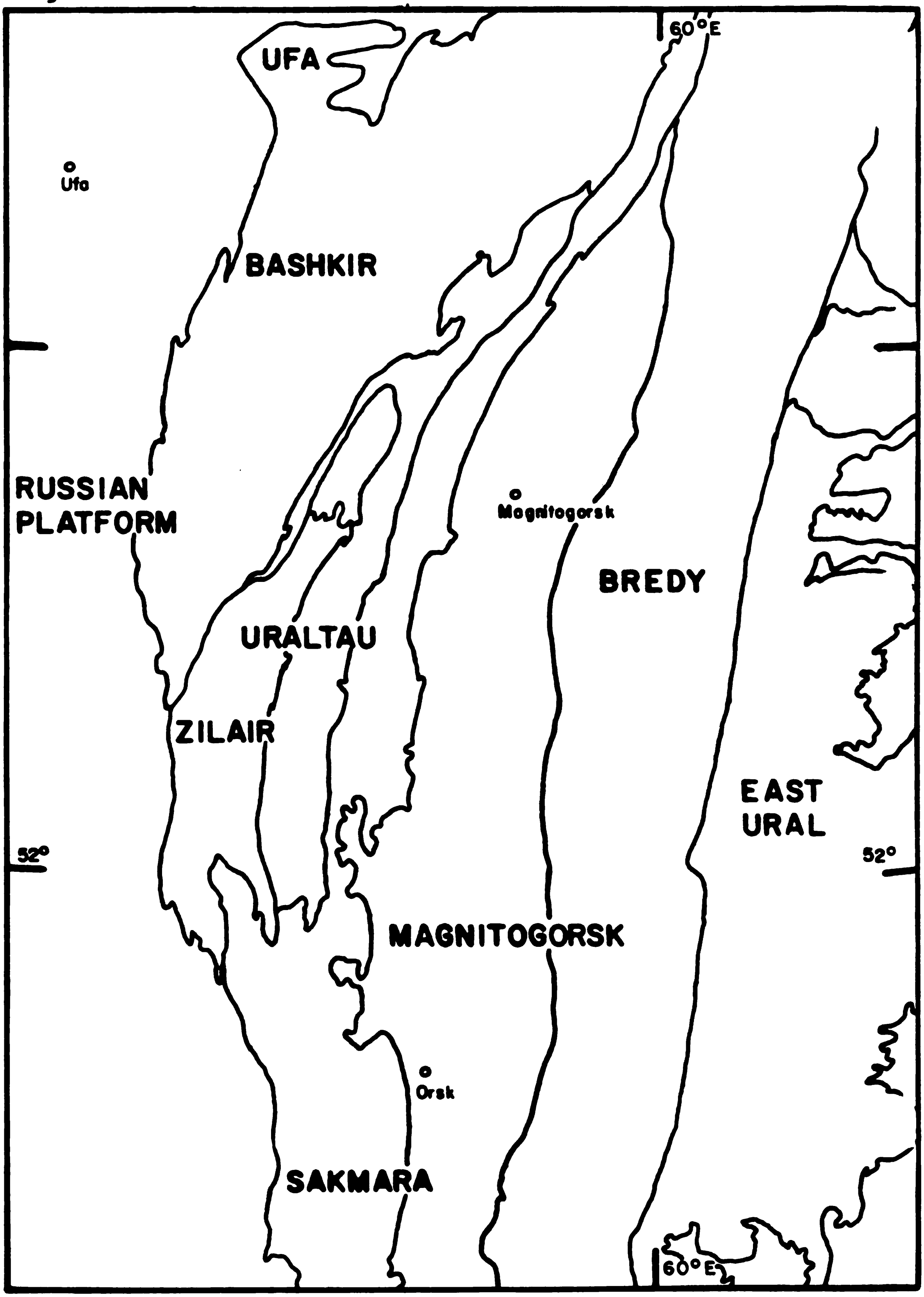
PREVIOUS SOVIET WORK

Horizontal tectonics are not completely unknown in the Soviet literature; thrusts, thrust faulting, and allochthonous masses are becoming more widely accepted and utilized in Soviet geologic interpretations. The use of overthrusts seems acceptable, although full scale subduction has appeared in the geologic literature only recently (Ruzhentsev and Samygin, 1979). The Sakmara region, Southern Urals (Figure 3), has been reconstructed using lateral motion of lithospheric "blocks" (Figure 4; Ruzhentsev et al., 1977), creating a model very similar to published works on the Appalachians. In comparing the Urals and Appalachians, Peyve (1973) describes the Polar Urals as having a very complete geologic section, as does the northern (Newfoundland) end of the Appalachians. The southern regions of both mountain chains are less complete. The ophiolites in both ranges are understood by Peyve (1973) to be tectonically emplaced; Peyve (1973) further suggests a global synchronism of principal tectonic stages of crustal development. The correlation of the Urals and Appalachians by Peyve (1973) provides details on the Urals and invites application of a new interpretation to the information provided.

Ivanov et al. (1975) describe a model of evolution which includes many plate tectonic concepts. In their model the Russian platform, Central Kazakhstania, and the

Figure 3. Terranes of the Southern Urals. For location of map see Figure 1.

Figure 3.


60°E
UFA
Ufa
BASHKIR
RUSSIAN
PLATFORM
URALTAU
ZILAIR
Magnitogorsk
BREDY
EAST
URAL
52°
52°
MAGNITOGORSK
Orsk
SAKMARA
60°E

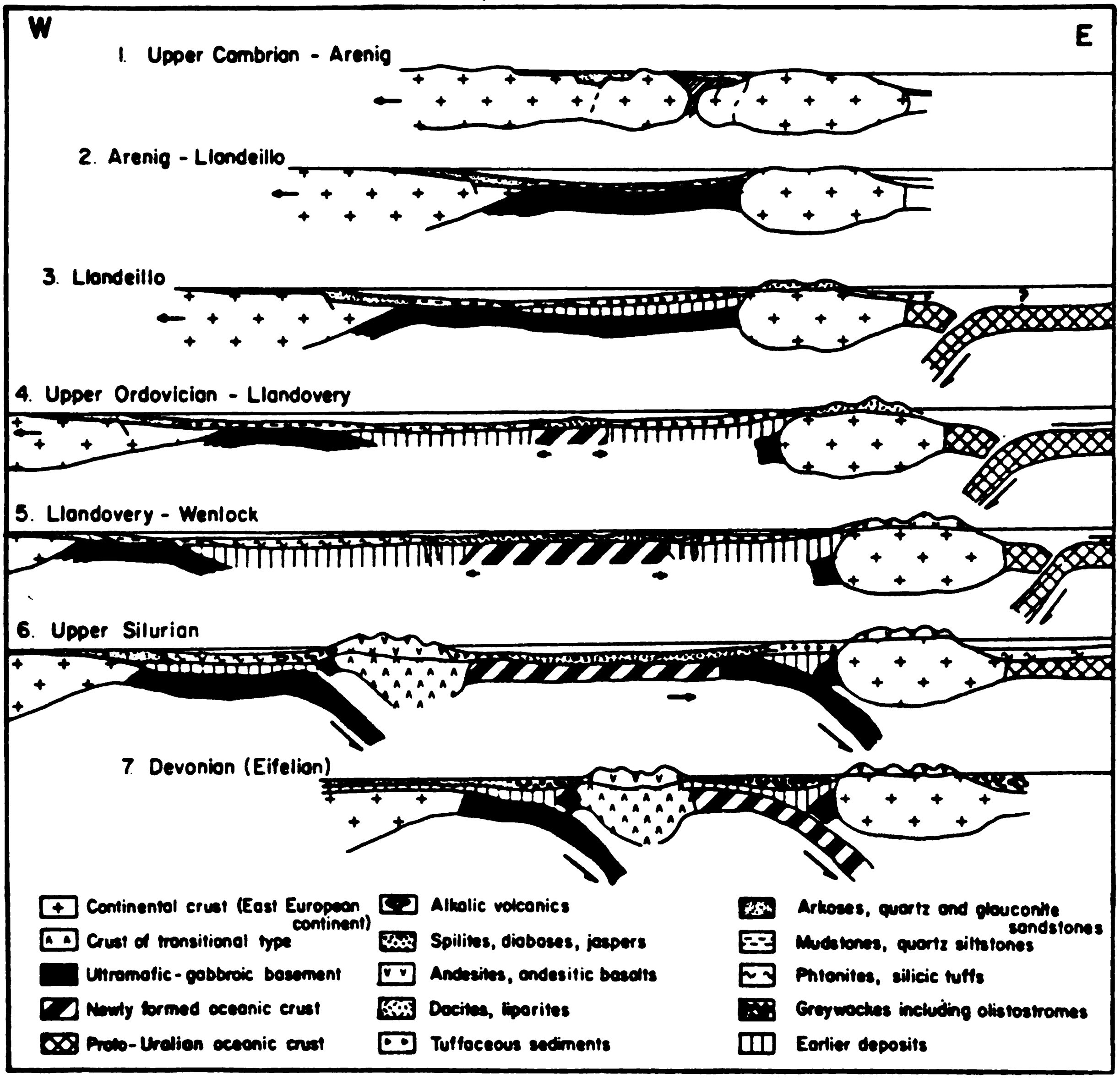


Figure 4. Tectonic development of the Sakmara trough. From Ruzhentsev and Samygin (1979).

Siberian platform represented one large craton during Vendian to Early Cambrian time. Breakup of the continent began in the Late Cambrian to Early Ordovician followed by development of oceanic crust in the intervening rift as evidenced by extensional features and a parallel (sheeted) dike complex with an accumulation of tholeiitic basalts and siliceous slate deposits. Rifting continued until Early Silurian time when spreading ceased, subsequent closure of the ocean emplaced compressional tectonic structures and diapiric ultramafics (Ivanov et al., 1975). This reconstruction obviously indicates a mode of formation for the obducted ophiolites currently observed in the geologic record.

Ruzhentsev and Samygin (1979) have also created a model of evolution for the Uralian region. Their mode of formation for the Urals is based on compression following extension that created a Uralian proto-ocean. This proto-ocean existed in the Late Riphean with closure beginning in the Vendian due to the initiation of westward dipping subduction. Early Ordovician rifting created a microcontinent which separated the Sakmara region from the ocean. A Late Ordovician spreading center created basaltic magmas. Spreading centers continued to exist into the Silurian with three separate spreading centers being recognized. Upper Silurian volcanics (spilites and diabases) were quite common as several central-type volcanoes existed. Silurian spreading centers continued into the Devonian. Island-arc development was extensive during the Devonian as arcs developed in zones this study has defined as the Magnitogorsk and Bredy terranes (Figure 3). Between these arcs, thoeliites were developed. The Bredy arc produced extensive calc-alkaline volcanism.

PREVIOUS AMERICAN WORK

World-wide Paleozoic continental reconstructions that cover the Urals have been published by various authors (McElhinny, 1973; Ziegler et al., 1977; Morel and Irving, 1978; Scotese et al., 1979; Ziegler, 1981). Hamilton (1970) dealt expressly with the Urals and associated regions and this has served as the first order horizontal plate tectonic model for that part of the world. Since that time, much new data have been made accessible to the west, filling the sometimes acknowledged, often present, data gaps and creating a need for a new analysis. Hamilton's (1970) main concept involves two continents colliding as an intervening oceanic plate subducted beneath them. Many of the features expected in a suture zone (Dewey and Bird, 1970; Ziegler et al., 1977; Fujita, 1978) are described by Hamilton, however, many of the processes described are unsubstantiated, i.e., using mountain chains with symmetric geology on either side to infer the presence of a continent-continent collision.

According to Hamilton (1970), the Russian subcontinent had a stable eastern margin with and island-arc located away from the continent during the Ordovician and Silurian periods. Subduction under this arc was dipping away from the Russian continent; such a geometry would demand the island-arc to be located on a separate plate. This arc collided with the continent in Early Devonian time with the suture zone being the Main Uralian Fault. The eugeosynclinal region was elevated and produced sediments which were deposited in the Devonian foreland basin adjacent to the Russian platform. A new west-dipping subduction zone developed oceanward of the accreted arc during the Middle to Late Devonian to accommodate continental convergence. This subduction continued until at least Early Permian. Oceanic sediments were scraped off the crust as subduction continued and the trench axis stepped oceanward, as did the main belt of calc-alkaline volcanism.

The Paleozoic of the western margin of Siberia was primarily a subduction zone with the Russian and Siberian plates colliding in Permian time.

Ziegler (1981) presents a series of figures which outline the paleogeographic movements of continents. Kazakhstania, Siberia, and Baltica (Russian plate) were widely separated in the Middle Ordovician. The Middle Silurian shows the plates coming closer with Laurentia also in close proximity. By late Early Devonian, Laurentia had become Laurussia as Laurentia and Baltica sutured. Kazakhstania joined with the Siberian plate by middle Late Carboniferous. Early Late Permian shows Kazakhstania (now sutured to Siberia) colliding with Baltica (now Laurussia). No suture is shown between Baltica and Siberia.

DATA SOURCES

The data for this thesis are taken from translations of Soviet literature and maps, consequently it entails the use of judgement to discern fact from interpretation. Often, interpretations are given as data based on the assumption that vertical tectonics control the situation.

Metamorphic rocks are often dated as Precambrian in the Soviet literature based on their metamorphic grade and the assumption that intense metamorphism has not taken place in the Phanerozoic. Radiometric dating has been done by many individuals and by the Academy of Sciences, U.S.S.R. The age data given, however, are often K-Ar dates and may not be consistent with the geology. Thus, care must be taken that the numbers are compatible with the geology. It must further be considered that the tectonic movements may create a situation where overlying rocks are older than the rocks beneath them.

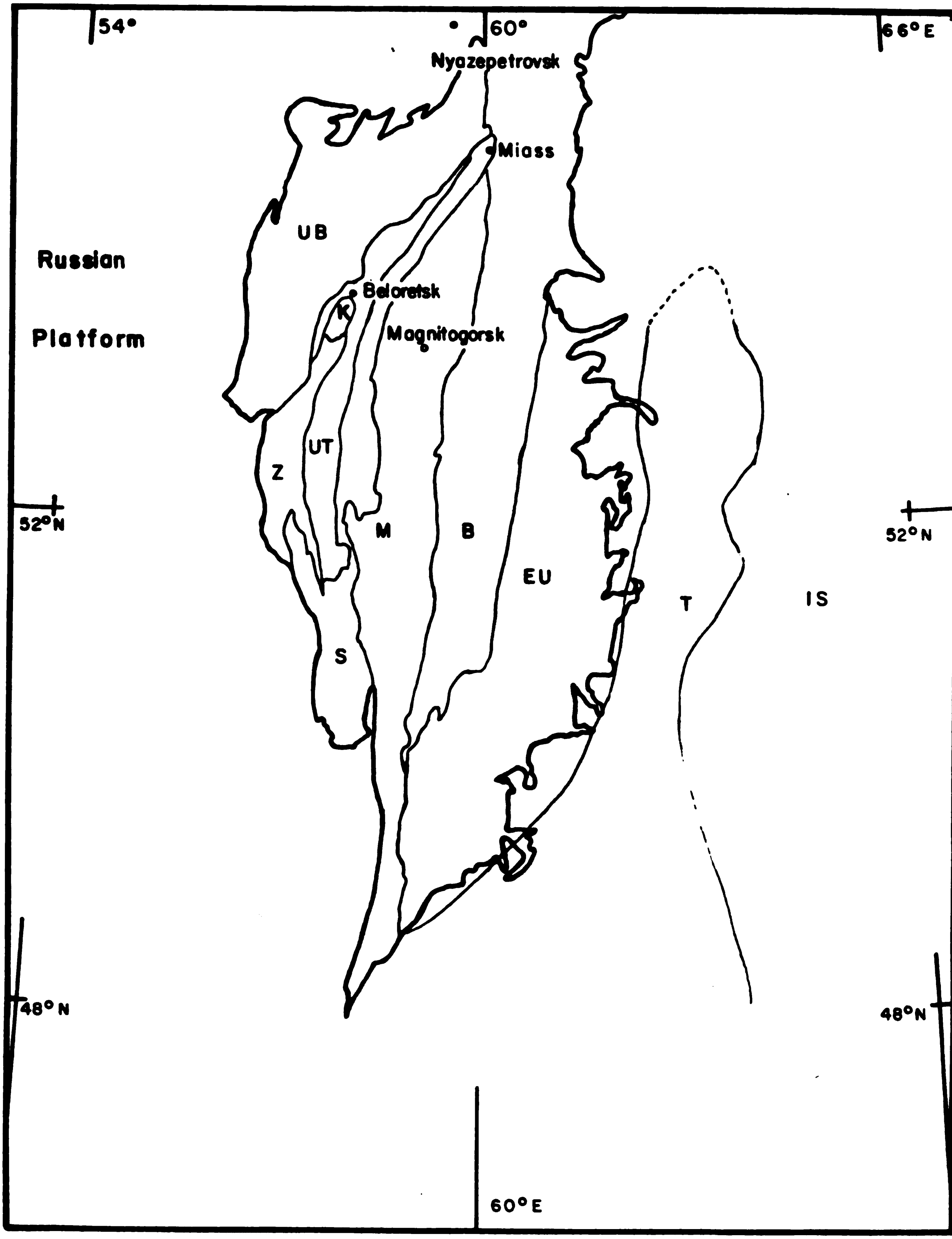
Ophiolite complexes have been extensively studied in the past 15-20 years and the Soviets have also made their contributions to this field. There are some Soviet geologists who believe ophiolites were once related to the oceanic crust. Peyve et al. (1977) describe both ophiolites and ocean floor as developing over a long time period accompanied by horizontal movements along various surfaces within the lithosphere. Others consider ophiolites special metamorphic formations (Lennykh et al., 1978), while still others, not necessarily Russian, suggest they are extrusive structures that have been rotated 90° to place the sheeted dike complex in a vertical orientation (Thayer, 1977). These different interpretations are easily reinterpretable to provide useful information.

IDENTIFICATION OF TECTONOSTRATIGRAPHIC TERRANES

Soviet subdivision of the Urals is found to correlate, for the most part, to western concepts of terranes. For this reason, some Soviet divisions have been utilized in this study; however, in several cases new terranes have been defined (i.e., Bredy, Turgay) to isolate regions with similar tectonostratigraphic evolutions. The Bredy terrane is the region the Soviet literature usually refers to as the West Magnitogorsk. Although the Soviets divide the west slope of the Urals into many zones, the east slope is usually treated as a single zone. In this study we separate the Soviet East Ural zone into three terranes, the Bredy, the East Ural, and the Turgay. Nine separate terranes are identified by this study; a list of these regions, arranged west to east is as follows (Figures 3 and 5):

a. Ufa-Bashkir terrane
b. Zilar terrane
c. Uraltau terrane
d. Sakmara terrane
e. Magnitogorsk terrane
f. Bredy terrane
g. Terranes of the East Urals
h. Turgay terrane
i. Ishim terrane

Figure 5. Division of the Southern Urals. Abbreviation of terranes: UB - Ufa-Bashkir; Z - Zilair; UT - Uraltau; S - Sakmara; M - Magnitogorsk; B - Bredy; EU - East Ural; T - Turgay; IS - Ishim. Other abbreviation: K - Krak Massif. The Krak Massif is interpreted as being part of the Sakmara terrane.



54°
60°
66°E
Nyazepetrovsk
Miass
UB
Russian
Platform
Beloretsk
K
Magnitogorsk
UT
Z
52°N
M
B
EU
T
IS
52°N
S
48°N
48°N
60°E

Figure 5.

The Turgay terrane is covered by the same mantle of sediments as the West Siberian Lowlands but is identified independently because of its unique subsurface lithology.

The geologic time scale adopted for this study (Figure 6) is taken from time periods used in the Lithological-Paleogeographical Atlas of the U.S.S.R. (Vinogradov, 1968, 1969). Absolute dates are from van Eysinga (1978).

Figure 6. Geologic time scale. Breakdown of time periods used in this study. Absolute dates from van Eysinga (1978). Periods subdivided into those used by Vinogradov et al. (1968, 1969).

	period	Ma	
	TRIASSIC	230	
PALEOZOIC	PERMIAN		Tatarian
			Ufimian & Kazanian
			Artinskian & Kungurian
		280	Asselian & Sakmarian
	CARBONIFEROUS		L. Carboniferous
			Moscovian
			Bashkirian
			Namurian
			Visean
		345	Tournasian
	DEVONIAN		Famennian
			Frasnian
			Gevitian
			Eifelian
		375	Early Devonian
	SILURIAN		Tiwer
			Ludlow
			Wenlock
		435	Llandovery
	ORDOVICIAN		Late
			Middle
		500	Early
	CAMBRIAN		Late Cambrian
			Majian
			Amginian
			Lenian
		570	Aldanian
PRECAMBRIAN			Vendian
			Late Riphean
			Middle Riphean
			Early Riphean

Figure 6.

UFA-BASHKIR TERRANE

The Ufa region (Figures 3 and 5) is semi-circular in shape, whereas most Uralian structures are linear. It is bounded on the east by the Bashkir terrane (Figures 3 and 5) and to the west by the Russian platform. The Bashkir terrane extends under the Cenozoic cover of the Russian platform. Data from a drill hole located 12 km southwest of Nyazepetrovsk (Figure 5) shows the geologic column consisting of limestone and dolomite capped by a formation of sandstone, limestone, and shale with a basal conglomerate (Figure 7). Paleontologic ages of these rocks show a complete section of Upper Devonian to Upper Bashkirian (C_2) (Figure 6) rocks. Underlying the above rocks, at a depth of 2000 m limestone and dolomite of Visean (C_1) through Frasnian (D_3) age rocks were encountered (Seliverstov et al., 1971). This lower group of carbonates is similar to the overlying limestones and dolomites. The two groups are interpreted to have been part of the same formation that have subsequently been thrust into their present positions. Based on these kinds of data Smirnov and Bellavin (1974) describe this region as a thrust region and delineate three separate thrust plates: First sheet - Silurian-Devonian carbonates (as discussed previously). Second sheet - the Bardym suite, consisting of Ordovician mafic rocks intruded by serpentinite, pyroxene and gabbro. These rocks are overlain by Late Ordovician-Silurian siliceous shale. This

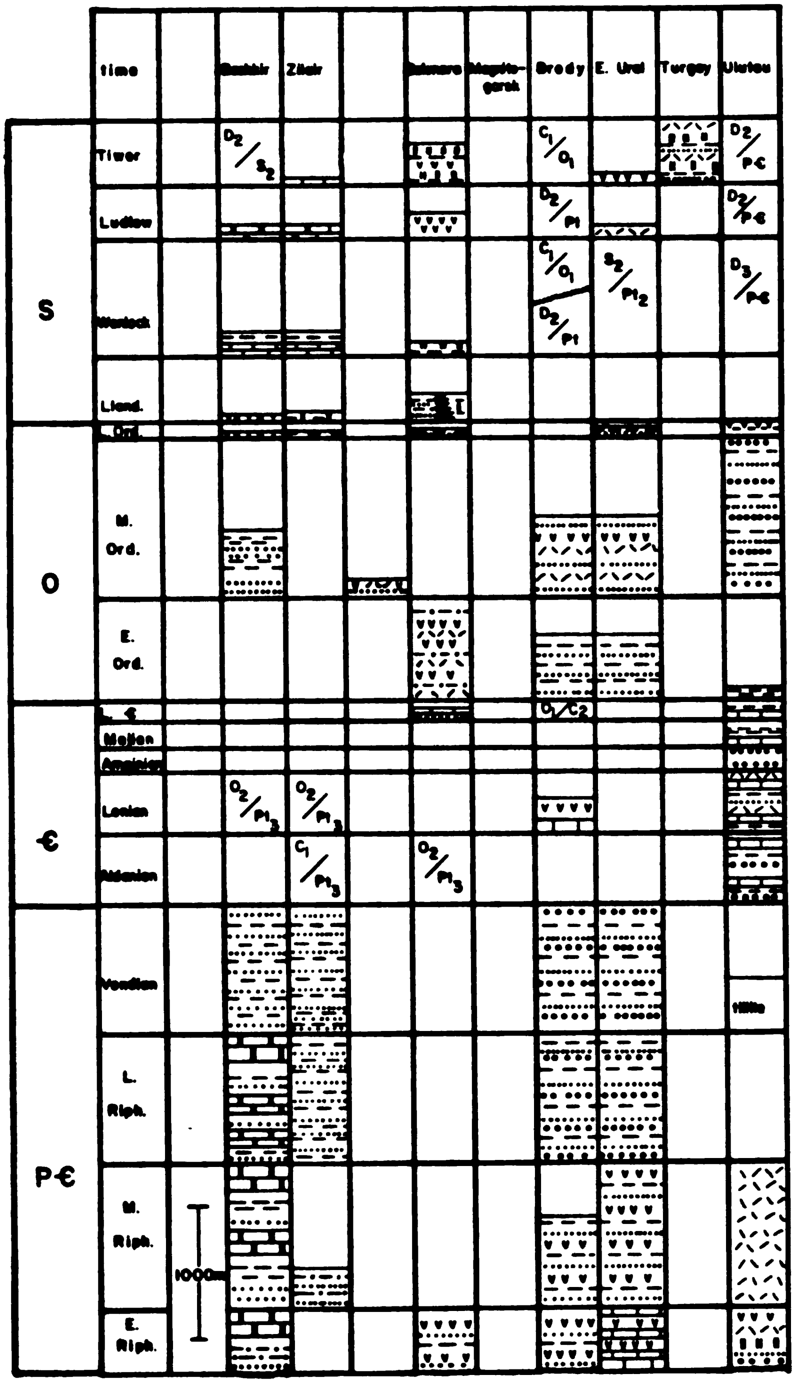
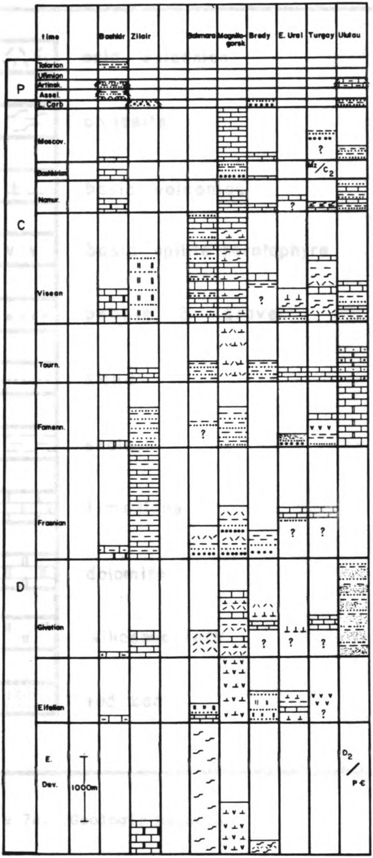


Figure 7. Geologic columns of the Southern Urals.

Figure 7. (cont'd)



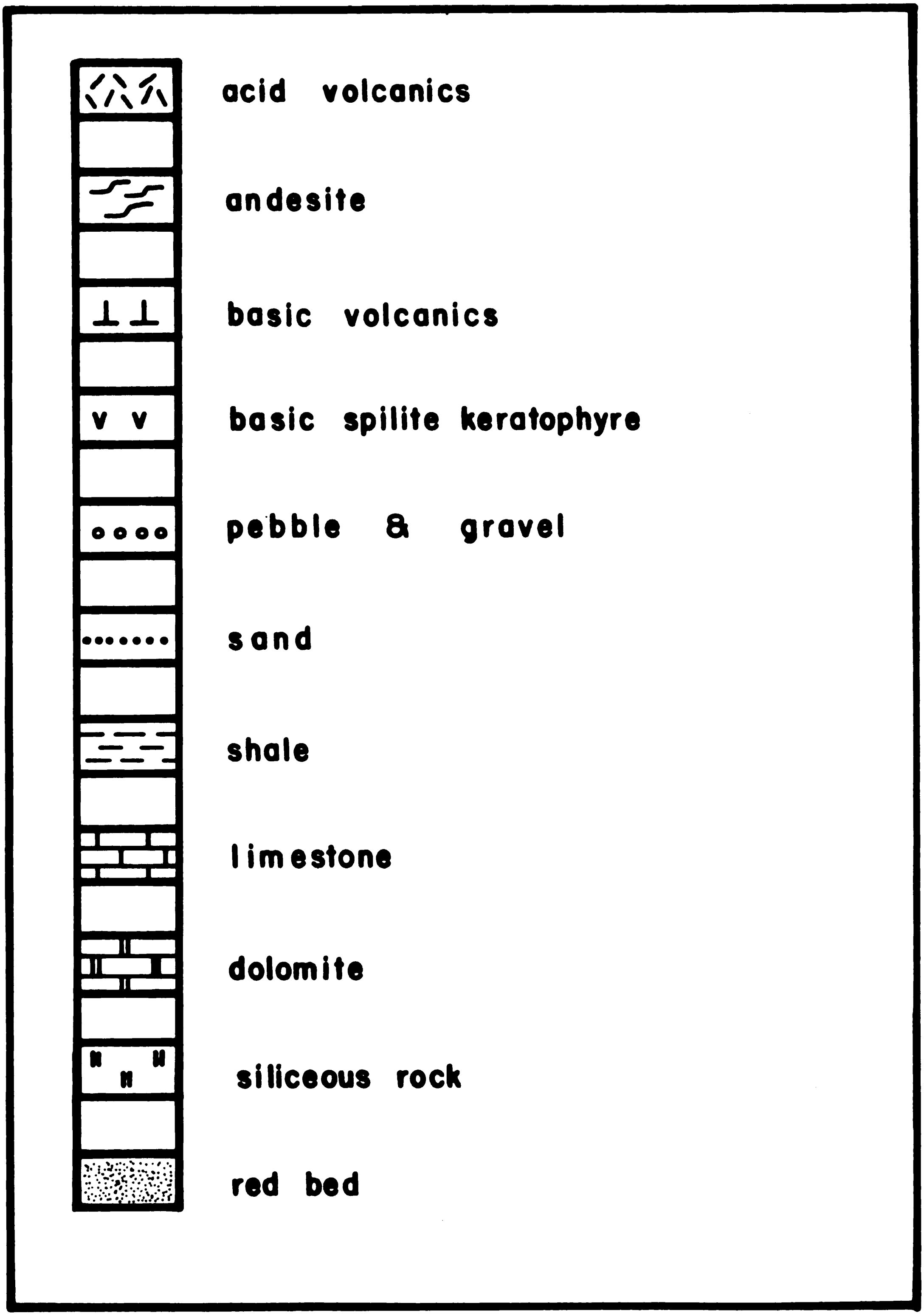


Figure 7a. Geologic symbols.

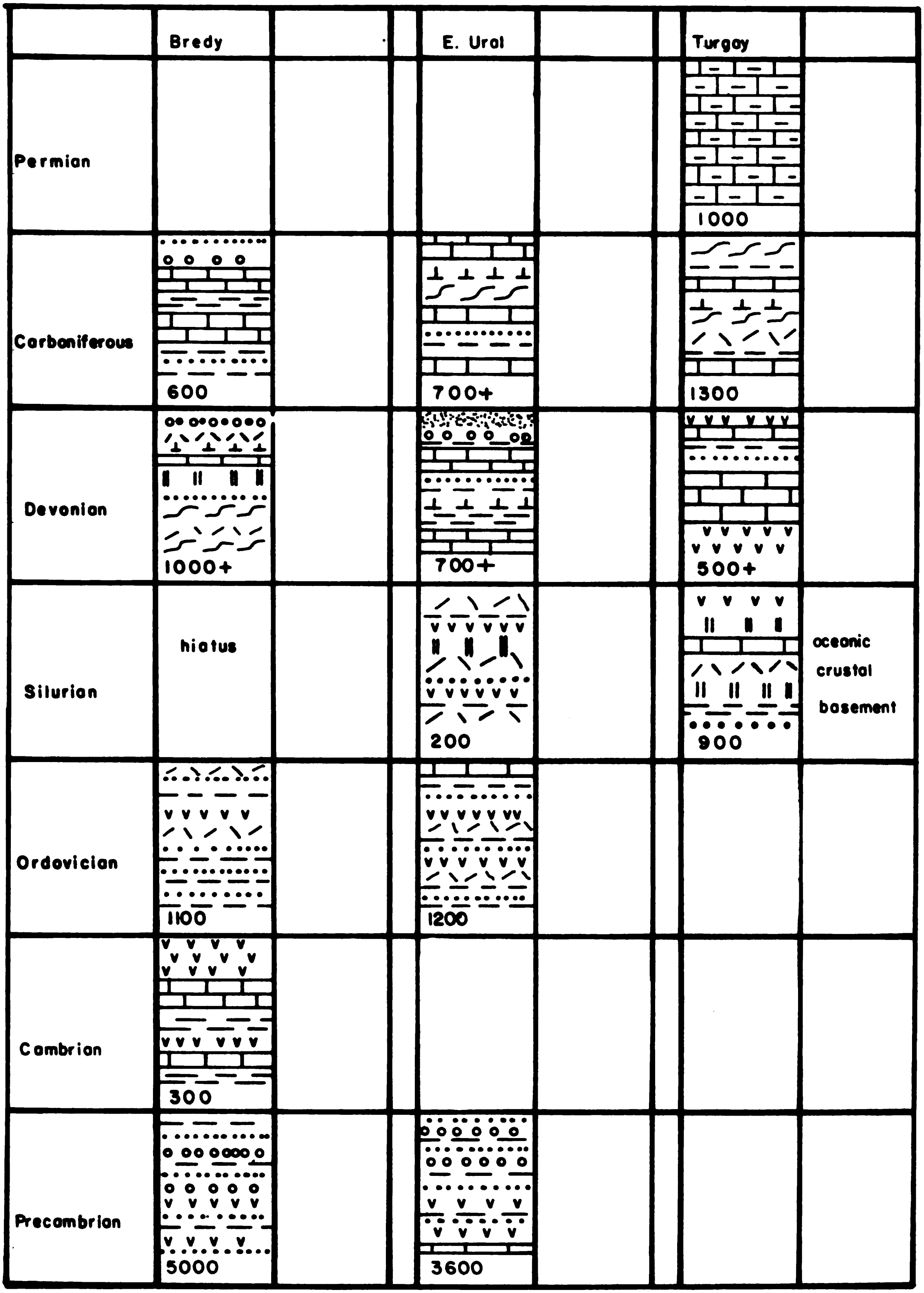
suite has several exposed gabbro bodies, the contacts of which dip toward the center with depth. Third sheet - Ordovician rocks in a gently dipping thrust over Devonian rocks. A geologic description of these rocks is not found in the Soviet literature. The direction of thrusting is east to west (Smirnov and Bellavin, 1974). This sequence may be interpreted as an initially passive margin where oceanic crust has been thrust onto platform carbonates, due to compressive forces, sometime after carbonate deposition.

ZILAIR TERRANE

The Zilair terrane, in the Southern Urals, is located to the east of the Bashkir region and to the west of the Uraltau terrane (Figure 3). The northern terminus of this zone is at the Krak massif (Figure 5). The geologic column for the Zilair terrane (Figure 7 and 8) shows a Riphean to Vendian sandstone and shale complex. Middle Ordovician sandstone and shale is separated from the Vendian rocks by an uncomformity (Vinogradov, 1968, 1969; Kamaletdinov, 1961). An unconformity between the Vendian and Middle Ordovician rocks appears as the most reasonable solution.

Devonian limestone (about 200 m) is overlain by the Zilair slate/shale of Famennian (D_3) to Tournasian (C_1) age, which has a maximum thickness of 400 m (Khat'yanov, 1976). Sediment transport was east to west during the Famennian (D_3) deposition of the Zilair formation, yielding sandstone in the east and siltstone in the west (Smirnov and Smirnova, 1960). Stratigraphically above the Zilair formation is Carboniferous flysch and Early Permian molasse (Kamaletdinov, 1961). No Precambrian crystalline basement is evidenced in the Soviet literature for this region. Kamaletdinov (1961) lists a metamorphic schist, Cambrian in age, as the basement for the east side and a period of erosion or nondeposition for the west. This region, based on lithology, can be interpreted as a passive continental margin which is overlain by siliceous sediments of a

Figure 8. Geologic columns of the Southern Urals. Select summary columns where adjoining columns represent the terrane listed as the heading of the left column. Left column is data taken from the Atlas (Vinogradov, et al., 1969). Right column provides additional information, where available from other sources. Numbers are thickness in meters.



Bredy
E. Ural
Turgay
Permian
1000
Carboniferous
600
700+
1300
Devonian
1000+
700+
500+
Silurian
hiatus
200
900
oceanic
crustal
basement
Ordovician
1100
1200
Cambrian
300
Precambrian
5000
3600

Figure 8.

Figure 9. Geologic columns of the Southern Urals. Symbols as in Figure 8.

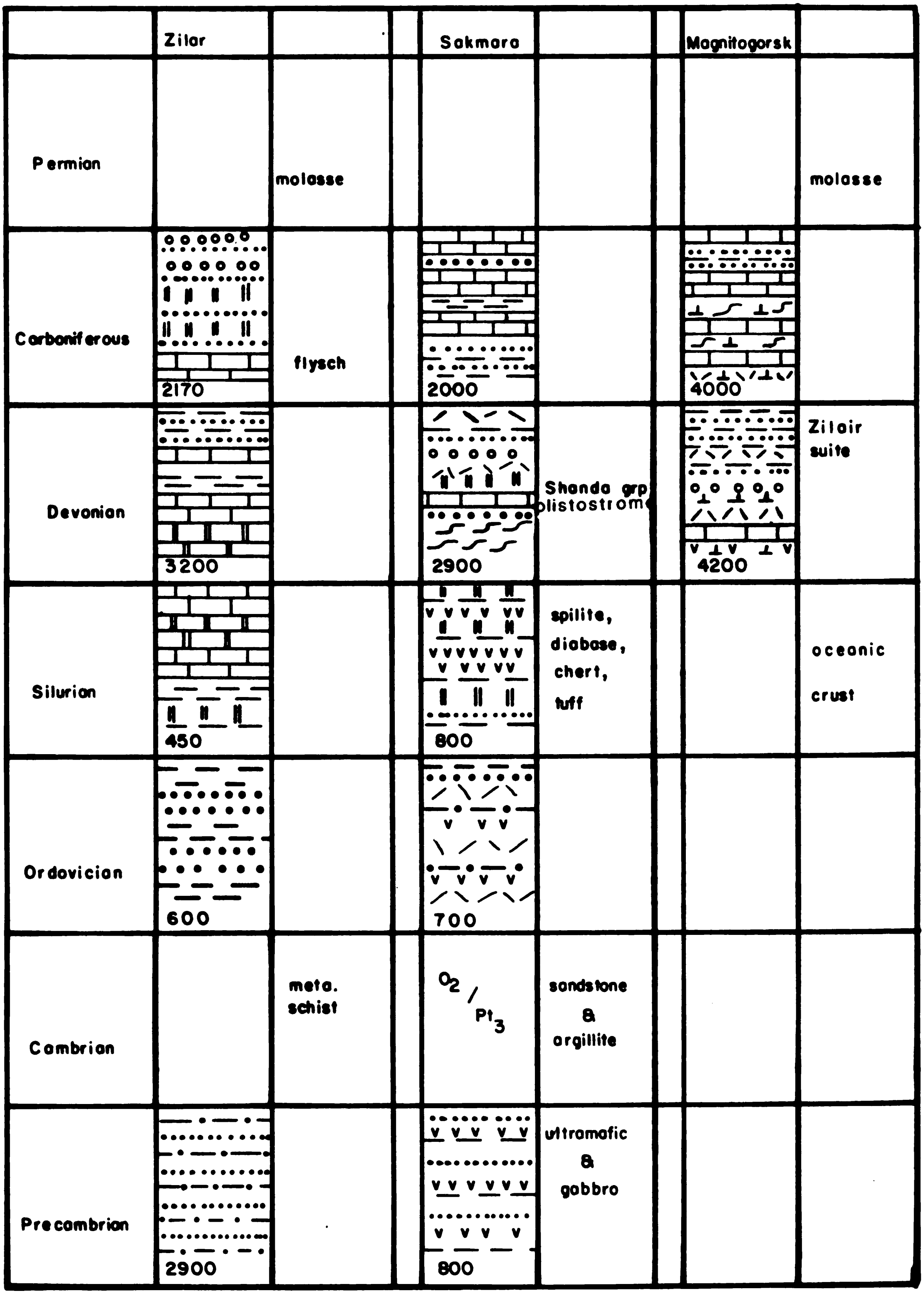

Zilar
Sakmara
Magnitogorsk
Permian
molasse
molasse
Carboniferous
flysch
2170
2000
4000
Devonian
3200
2900
Shanda grp
olistostrome
4200
Zilair
suite
Silurian
spilite,
diabase,
chert,
tuff
oceanic
crust
450
800
Ordovician
600
700
Cambrian
meta.
schist
O_2 / Pt_3
sandstone
&
argillite
Precambrian
ultramafic
&
gabbro
2900
800

Figure 9.

transgressing sea or an inactive marginal basin. A Late Carboniferous turbidite sequence indicates the final stage of shallower water continental sedimentation.

URALTAU TERRANE

In the Southern Urals, the Uraltau terrane is located between the Zilair and Sakmara terranes. The west slope of the Middle and Northern Urals is often also called the Uraltau region in the Soviet literature. The terrane is composed primarily of metamorphic rocks which were metamorphosed during the obduction of the Sakmara Ultramafic. These schists have been dated as Lower and Middle Riphean (Alekseyev, 1976), however this age is probably assigned on the basis of metamorphic grade, rather than by analysis of regional geology. The rocks to the east are part of the Sakmara terrane, but to the west of the Uraltau schists are Silurian age rocks in conformable contact, indicating the Precambrian age is erroneous.

The Uraltau terrane was the eastern-most edge of the passive margin of the Russian platform. The terrane originated by the horizontal stresses of the subduction located to the east. This stress is evidenced by the predominantly metamorphic rocks: quartzite, schist, gneiss, eclogite, and marble all of which are folded into large scale folds.

SAKMARA TERRANE

The Sakmara zone (Figure 3) is usually included as the western edge of the Magnitogorsk megasynclinorium, but is here treated as a separate unit because of its unique geologic makeup and tectonic mode of formation. It is generally agreed the northern part of the Sakmara zone is 20 to 30 km wide, with the southern portion increasing in width. Length of the Sakmara terrane ranges from 200 km (Ruzhentsev, 1972) to 400 km (Kamaletdinov and Kazantseva, 1978). The southern terminus is located just south of the city of Orsk (Figure 3); it is the northern boundary that is disputed. According to Ruzhentsev (1972) the Sakmara zone ends at Beloretsk (Figure 3), but Kamaletdinov and Kazantseva (1978) suggest it continues to parallel the Magnitogorsk terrane northward to the city of Miass (Figure 5). The Soviet geologic maps (1:1,500,000, 1972; 1:1,250,000, 1965) indicate no such continuation. This study defines the Sakmara as ending about the region of Miass, with the southern terminus extending farther south than either Ruzhenstev (1972) or Kamaletdinov and Kazantseva (1978) indicate. For this reason, the terrane is about 500 km long. This definition of the Sakmara terrane is employed since the southern area is most similar to the Sakmara terrane, and less closely related to surrounding terranes.

Various terminology has been applied to the Sakmara region which has resulted in confusion. Sakmara zone is a general term often used by Russian authors to define a region that has no universally accepted boundaries. This "zone", at some time in history, was covered by water and therefore is referred to as the Sakmara basin. This study has utilized three additional terms in an attempt to clarify the situation with definite boundaries. The Sakmara terrane is an area designed to fit the definition of the word terrane (see Figure 5 for boundaries). The Sakmara allochthon is the discontinuous west arm of the Sakmara terrane of which the Krak massif is the northern exposure. The Sakmara ultramafic is the east arm of the Sakmara terrane (Figure 3).

The geologic column (Figure 8) for the Sakmara region shows the base to be Cambrian to Early Ordovician subarkosic sandstones and argillites of the Kidryasovo suite (Pospelov and Ruzhentsev, 1972) overlying gabbroic and ultramafic rocks (Khvorova et al., 1975) presumed to be oceanic crust. Overlying the sandstones and argillites is a terrigenous-cherty-tuffaceous sequence, now in a vertical section, originally consisted of Early Ordovician to Early Silurian mudstones and siltstones of the Kurgan group in the west and the Kos Istek formation in the east. The Kos Istek formation is divisible into the Late Ordovician to Early Silurian Guberlinskii group of tuff, jasper, and acid and basic volcanics and the overlying tuffaceous sequence of the Kos Istek group (Khvorova et al., 1975).

The Ordovician rocks are overlain by a Silurian volcanic-cherty complex which is composed of five groups of rocks: (west to east) the Sakmara group, Khersonkovskii group, Baiterekskii group, Blyavenskii group, and the Sugrala group. The Sakmara and Khersonkovskii groups are primarily limestone, chert, and flysch while the other groups are chiefly spilite, diabase, chert, and tuff. This section can be interpreted as an oceanic sedimentary section.

An olistostromal sequence (Shanda group) dated Early Devonian to Eifelian (D_2) consists of conglomerate and sandstone with limestone and chert, and basalt and tuff. The Shanda group better fits the geologic column if the strata discussed above form a system of very intricately folded tectonic plates (Pospelov and Ruzhentsev, 1972). Kamaletdinov and Kazantseva (1978) have redefined the age of a Visean (C_1) limestone and basic and intermediate volcanic sequence as Devonian age. These rocks may be interpreted as an oceanic sequence with the overlying Shanda group representing a turbidite from a then present shelf edge.

Structurally the Sakmara terrane is a homoclinal thrust sheet where Zilair suite (D_3) graywackes are thrust from the east over Late Tournasian (C_1) to Early Visean (C_2) limestones (Kamaletdinov and Kazantseva, 1978). Using available data these Zilair suite rocks can be correlated to the Zilair suite in the Magnitogorsk terrane, however, they no longer lie in proper stratigraphic succession. The Zilair suite rocks cover large thrust sheets and extrusive and siliceous rocks of the Betrya suite along with ultramafics that "intrude" the sequence (Smirnov and Bellavin, 1974). The Betrya suite may be interpreted as an ophiolite sequence. The western boundary of the thrust sheet is the ultramafic belt that extends from Orsk to Beloretsk (the Miass-Sakmara deep fault, Figure 5). To the east the boundary is buried under the Irendyk formation (see Magnitogorsk section) of the Magnitogorsk zone. Levitan (1978) interprets these andesite-basalt volcanics as the result of an island-arc stage during the Late Silurian and Early Devonian.

MAGNITOGORSK TERRANE

The Magnitogorsk terrane (Figure 3), South Urals, is bounded on the west by the Sakmara zone, a region often considered as part of the Magnitogorsk terrane by some Soviet authors, but identified as a separate terrane in this paper. To the west lies the Bredy terrane (Figure 3), a region usually included as the west side of the Magnitogorsk region. A separate geologic column has been compiled for the Bredy zone (Figure 9).

In the Soviet literature the Magnitogorsk terrane is often referred to as the Magnitogorsk synclinorium or megasynclinorium. These two terms, by definition, are not equivalent (see Appendix B) creating confusion about the size of the region. The Tagil zone (Figure 13), Central Urals, is often considered a continuation of the Magnitogorsk zone by some Soviet authors, but Ivanov et al. (1973) state that Tagil is not a structural continuation, but rather a tectonic juxtaposition. Khalevin et al. (1969) point out that the Paleozoic section joining the Magnitogorsk and Tagil terranes does not thicken toward the center (by deep seismic sounding (DSS) data) as a continuous syncline should, and further there is not consistent change in outcrop age.

The geologic column of the Magnitogorsk terrane shows no rocks older than Early Devonian (Figure 8). These Early Devonian rocks are basic and basic spilite-keratophyre volcanics extending through the Eifelian (D_2) where they are overlain by Givetian (D_2) limestone and acid and basic volcanics. The overlying Frasnian (D_3) sequence consists of acid volcanics, pebbles, sand, and shale which is overlain by Famennian (D_3) sand and shale. This sequence can be interpreted as an island-arc environment with volcanism ending in the Frasnian (D_3), followed by a coarse clastic sedimentation grading into shale sedimentation. During the Tournasian (C_1), rejuvenation of volcanism deposited acid and basic volcanics which grade into Visean (C_1) intermediate and basic volcanics with limestone, Namurian (C_2) limestone, Bashkirian (C_2) sand and gravel, and Moscovian (C_2) limestone. These rocks may be interpreted as more mature volcanics and andesites grading into a platform sequence of limestones that was interrupted by a clastic sequence. Smirnov and Smirnova (1960) describe the Magnitogorsk as containing volcanic sedimentary sequences of sedimentary rock, tuff, and tuff-breccia alternating with sheets and flows of silicic , mafic, and intermediate extrusives. Among these rocks is the Irendyk formation (D_2) that Levitan (1978) interprets as part of as island-arc stage. The Karamaltash series of the Eifelian (D_2) (Gorokhov et al., 1962) age basaltoid rocks have differentiation products analogous to sodic rhyolites and dacites of present ocean basins (Na_2O/K_2O ratio greater than 4 to 5) (Ivanov et al., 1975). The Zilar suite is a Famennian (D_3) to Early Tournasian (C_1) (Arzhavitina, 1976) volcanic and clastic formation (Prokin and Ogarinov, 1975) which, in the western Magnitogorsk region (Bredy terrane) becomes 500-1300 m of entirely flyschoid sediments (Arzhavitina, 1976). Prokin and Ogarinov (1975) describe a Silurian spilite-diabase sequence (which may correlate to Early Devonian on the geologic column, Figure 7) which have high TiO_2 content (1.3-1.7%), similar to ocean basalts, have a large areal extent, are low in pyroclastics and are associated with siliceous sediments. Such a geologic description can be interpreted as indicating a deep sea origin at a spreading center or a marginal basin.

The spatial migration of volcanic belts from west to east (Prokin and Ogarinov, 1975) is supported by a plot of andesite locations (Figure 10) in the Paleozoic taken from the Lithological-Paleogeographical Atlas of the U.S.S.R. This migration of andesites may be suggestive of the direction and sequencing of events of the Uralian subduction complex.

TERRANES OF THE EASTERN URALS

The East Ural zone (Figure 3) is defined by the Soviets to extend from the Southern to the northermost Urals. Unlike the west slope, it is seldom broken into subdivisions by the Soviets. On the basis of geologic evidence presented in Figure 5, it is apparent that the East Ural zone should be subdivided into at least three terranes: the Bredy, lying just east of the Magnitogorsk terrane , the East Ural, forming the core of the East Ural zone, and the Turgay, which extends under the sedimentary cover of the West Siberian Lowlands. Between the Turgay terrane and Kazakhstania proper, the existence of another terrane, the Ishim, may be postulated.

The Bredy terrane is separated from the East Ural terrane by a band of granites and ultramafics while the Turgay terrane has a lithology distinct from the East Ural terrane until Tournasian (C_1) time (Figures 7 and 9). Data from the Turgay terrane are sparse and consist mainly of exposures along rivers and data from drill holes.

The Turgay terrane can be interpreted as having oceanic crustal basement overlain by Early Devonian basic volcanics. These rocks are overlain by Givetian (D_2) and younger clastics and carbonates with occasional interbedded acid volcanics and andesites.

The East Ural terrane has Ludlow (S_2) age basic volcanics overlain by Tiwer (S_2) basic spilite-keratophyre volcanics. Volcanism ceased with Eifelian (D_2) and Givetian (D_2) basic volcanics; thereafter minor deposition of andesite volcanics interrupted platform type deposition. During the Tournasian (C_1) the Bredy, East Ural, and Turgay terranes formed an east-to-west sequence that fined to the west. Pebbles, sand, and shale cap Bredy terrane volcanics, with the last volcanics being Namurian (C_2) andesites in the Turgay terrane.

To the east of the Turgay terrane is the Ishim terrane, completely covered by Mesozoic and Cenozoic sediments, which has been defined through the existence of Visean and Namurian (C_2) age volcanic deposits. These rocks are primarily andesites and a graph of the location of them is included as Figure 10. These andesites were the primary basis for the definition of the Ishim terrane.

Precambrian rocks exposed in the southernmost portion of the East Ural terrane have been interpreted as material rifted from the Russian Platform (Ruzhentsev, 1972). Comparison of the lithology of these two regions (Figure 7) show the rocks to be dissimilar and therefore the origin of the East Ural terrane should not be interpreted as one of rifting from the Russian Platform.

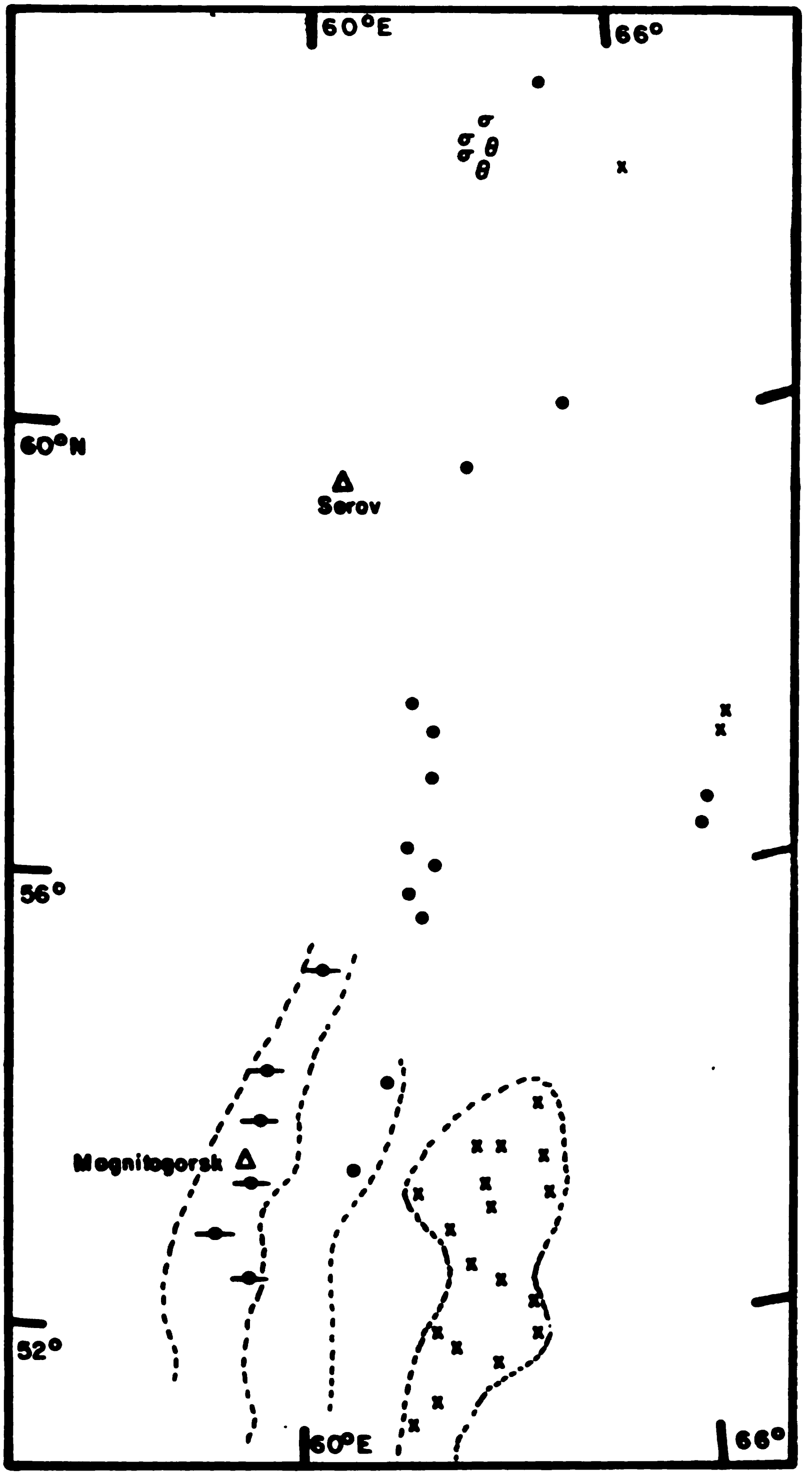


Figure 10. Distribution of andesites in time and space.
Dotted lines represent boundaries between terranes.

σ - Ordovician
θ - Silurian
-●- - Early Devonian
● - Late Devonian
x - Carboniferous

WEST SIBERIAN LOWLANDS

The West Siberian Lowlands have been well described by various authors (Tamrazyan, 1971; Kosygin and Parfenov, 1975; Bazanov et al., 1976; Rudkevich, 1976; Meyerhoff, 1980), consequently only selected information will be discussed. No granitic crystalline basement is reported in the Soviet geologic literature. The Triassic to Recent sedimentary mantle that covers the Lowlands is 8-12 km thick (Kulikov et al., 1972; Bochkarev and Rudkevich, 1975) with the deepest region being the Yenisey-Khatanga trough (Kosygin and Parfenov, 1975).

Data from a drill hole near the center of the Lowlands shows a porphyry and tuff-lava formation, with quartz stringers, at a depth of 3000 m dated by the comparative birefringence dispersion method (on plagioclase) as 326 ± 6 Ma (Early Carboniferous) (Bochkarev and Pogorelov, 1968).

Seismic reflection and refraction data shows an intermediate zone exists between the mantle of sediments covering the Lowlands and the basaltic basement. This zone varies in thickness from 2 to 4 km and has folds where limbs dip 2°- 6° (Bochkarev and Rudkevich, 1975). Trofimuk et al. (1973) suggest the intermediate zone is up to 10 km thick and contains oil and gas. A seismic profile has been interpreted by Krylov et al. (1973) suggesting reflecting boundaries at 4-5 km, 20-23 km and the Moho at 40 km. Seismic P-wave velocities are: 5.8 km/sec for layer 2, 6.2

km/sec for layer 3 and 8.0 km/sec below the Moho.

Based on seismic and drill hole data, the West Siberian Lowlands can be interpreted as a region devoid of a granitic crust. Mesozoic and Cenozoic sediments fill the region floored by oceanic crust which exists due to cessation of subduction, prior to continent-continent collision, in the Late Paleozoic.

KAZAKHSTANIA TERRANE

Kazakhstania (Figure 1) is presently located east of the Southern Urals and is composed of several different structural-stratigraphic units (Figure 11). Koshkin (1969) divides Kazakhstania into eastern and western sections separated by the Central Kazakhstan strike-slip fault which runs northward from the east end of Lake Balkash and is proposed to be part of a strike-slip fault that extends from south of India to Northern Siberia. Antonyuk et al. (1977) provide a more practical division which runs along the eastern slope of the Kokchetav and Ulutau (Figure 11) regions creating the Kokchetav block and the Balkash region (which includes the Karatau region (Figure 11)). This study further divides the eastern Kokchetav region into the Kokchetav, Teniz and Ulutau regions (Figure 11).

The Kokchetav and Ulutau regions have granitic crust which is Riphean in age based on radiometric dates of .95-1.2 Ga on granite-gneiss zircon and 1.2-1.4 Ga on metamorphic zircon (Pavlova, 1978). The present crust of the Kokchetav region is thick (50-55 km) where 35 km of that thickness is attributed to the basaltic layer (Rozen et al., 1974; Rozen, 1977) based on deep seismic sounding (DSS) data. These features are not seen in the Teniz basin, rather, an intense magnetic anomaly, relatively low gravity values, thin crustal layer (35 km) and a thin basaltic layer are observed (Zeylik and Seymuratova, 1974). Based on DSS

Figure 11. Terranes of Kazakhstania. Dashed lines are inferred boundaries of terranes.

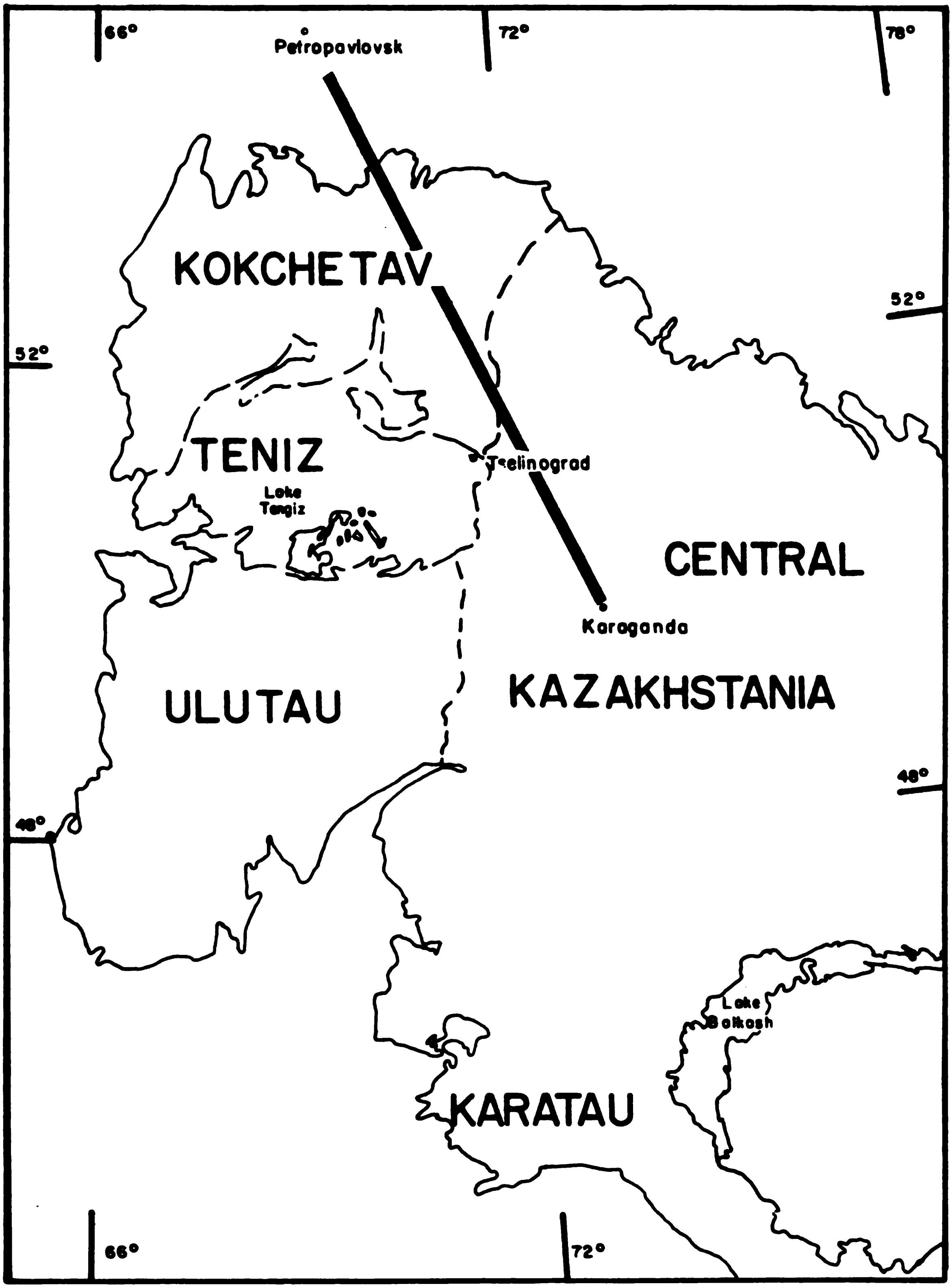

66°
Petropavlovsk
72°
78°
KOKCHETAV
52°
52°
TENIZ
Tselinograd
Lake Tengiz
CENTRAL
Karaganda
ULUTAU
KAZAKHSTANIA
48°
48°
Lake Balkash
KARATAU
66°
72°

Figure 11.

data Zeylik and Seymuratova (1974) infer the existence of a 200 km diameter upward bulge in the Moho and Conrad discontinuities. Soviet authors have interpreted this region as an uplift, a downwarp and as a meteorite impact structure, however an alternative interpretation is that the region lacks continental crust and is therefore a "hole", currently filled with Cenozoic sediments, to the basalt layer.

Ophiolites are found on the west edge of the Ulutau region and the north and northwest edge of the Kokchetav region. Abdulin et al. (1974) suggest these ophiolites are Riphean in age, while surrounding eclogite is dated at 1.35 Ga (no specific method of age dating is provided). Ophiolites of the Kokchetav region are dated by Rozen (1977) at 1 Ga. In an alternative model, Zonenshayn (1973) suggests these ophiolites were emplaced during the closing of the Uralian suture; coincident with this closure was the formation of a marginal basin in the area of what is now Central Kazakhstan. This marginal basin would provide a source for creation of an ophiolite.

Volcanics of the Ulutau region are rhyolites with high K_2O content suggesting a mature crust, however, effusive volcanics of this region seldom mature as far as andesites (Pavlova, 1979). Serpentinite bodies of the Ulutau are associated with amphibolite and/or greenschist facies metamorphism and are shattered and foliated where foliation planes dip 40°- 70° west (Pavlova, 1979). These westward dipping foliations agree with the curvature of the island arc and transform faults in reconstructions published by Zonenshayn (1973). Westward dip of the foliations tends to indicate this region is on the east side of an orogen and low grade, mostly pressure metamorphism tends to indicate a compressional zone where, as first suggested by Zonenshayn (1973) and later supported by Ziegler et al. (1977) an incomplete collision took place creating a noticeable lack of high-grade metamorphism.

The seismic cross-section depicted in Figure 12 shows a break in the stratigraphy at the boundary of the Kokchetav region and the West Siberian Lowlands. This break may be interpreted as the edge of the Kokchetav craton and the compacted sediments of the Lowlands. Note the rise in the Moho discontinuity in the region of Petropavlovsk, which outlines the edge of the continental material.

The suturing of Kazakhstania and the Siberian plate occurred during the Early to Middle Cambrian. Southwestward subduction under Kazakhstania is inferred from the volcanic rocks in the geologic record according to Vinogradov (1968). Eastern Kazakhstania is outside the main area of this study but it is in itself an interesting study which should be conducted.

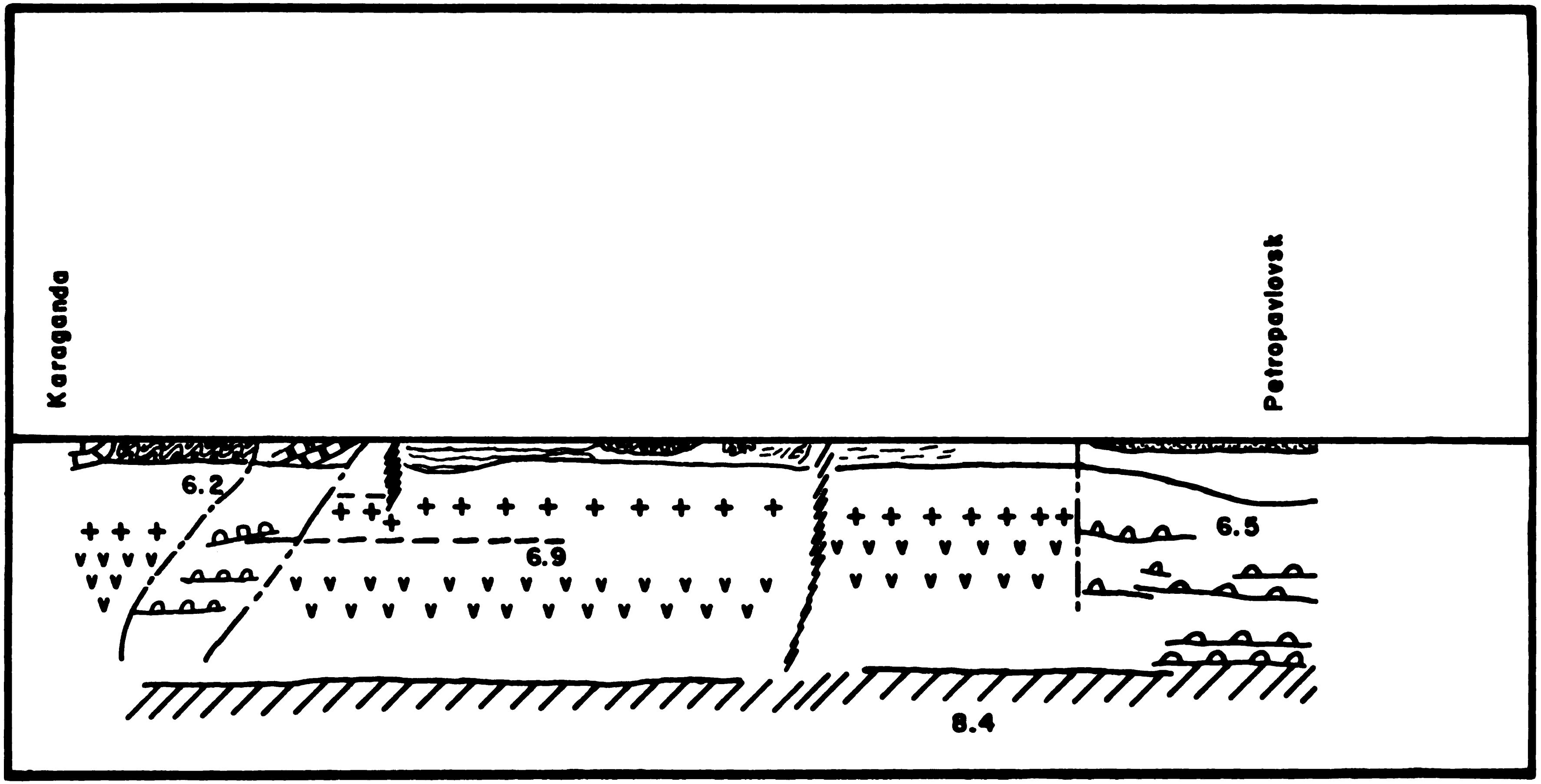


Figure 12. Seismic profile: Karaganda to Petropavlovsk. For location see Figure 11. Numbers are seismic velocities in km/sec. Symbols are as follows:

Moho discontinuity

reflecting horizons

major tectonic disturbance

--- seismic boundary

possible tectonic disturbance

(after Antonenko & Dubrovin, 1969)

TAGIL TERRANE

The Tagil terrane (Figure 13), often considered part of the Magnitogorsk megasynclinorium, encompasses most of the physical relief of the Middle and Northern Urals. The southern boundary is at the latitude of Sverdlovsk (Figure 13). The western boundary is marked by deep faults and the east by the Serov-Mauk ultramafic belt. The geology has been described by Khalevin and Chervanyakovskiy (1970) as three structural facies zones: the eastern Krasnoural'sk, the Middle, and the western Kabanka zones. The Krasnoural'sk zone is an andesite-basalt association dipping east 70°- 80° and is Ordovician to Llandoverian (S_2) in age. The Middle zone is composed of andesite-basalt, trachyandesite-basalt, tuff-flysch, and volcanic molasse dipping east 10°- 20° and Wenlockian (S_2) to Early Devonian (D_1) in age. The Kabanka zone is a pyrite-bearing region much like the Krasnoural'sk region with a similar dip. This eastward dip, also noted by Karetin (1967), can be interpreted as indicating this region to be to the west of the axis of the zone of compression. Sokolov et al. (1974) describe the eastern regions to be thrust over the western zones. In the central zone of the Tagil, Karetin (1967) describes spilites (subalkaline basalts) interbedded with alkaline-poor diabase of Wenlockian (S_2) age.

A seismic reflection survey, in the Tagil zone, interpreted by Sokolov et al. (1974) shows a velocity

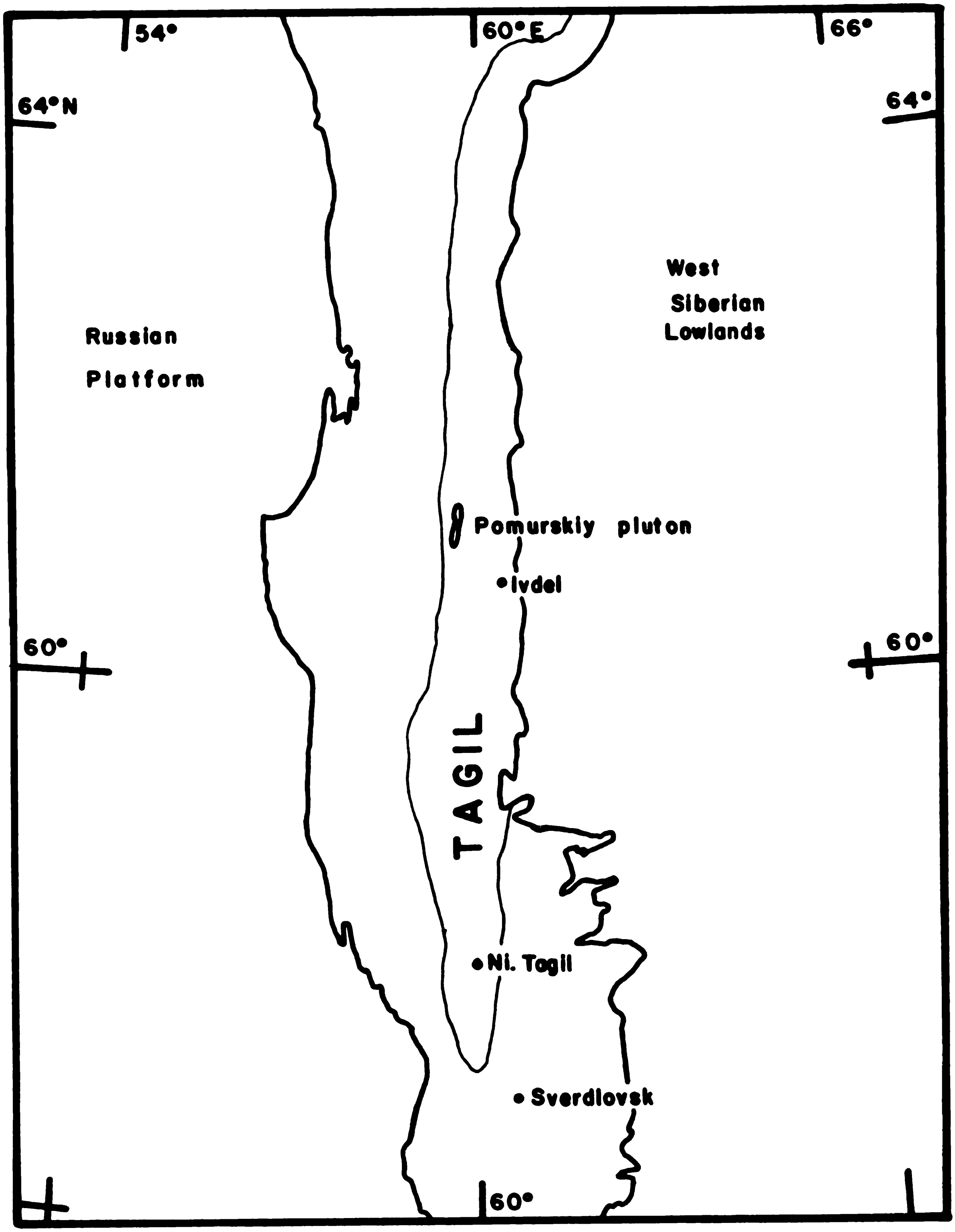


Figure 13. Central and Northern Urals. Outline of Tagil terrane and ultramafic Pomurskiy pluton.

section of the Central/Northern Urals at the latitude of Ivel (Figure 13). The survey line originates in the Pomurskiy gabbro pluton (Figure 13), listed on the Soviet geologic maps as an ultramafic, to the edge of the West Siberian Lowlands. Ultramafics appear at the base of the west side of the cross-section with overlying gabbro and granodiorite. These rocks dip east at about 30°. On the east side of the cross-section, volcanic and sedimentary rocks dip eastward but are heavily faulted. The fault pattern is similar to the shearing fault pattern observed in a melange. Sokolov et al. (1974) suggest the diorite and quartz-diorite intrusions piercing the gabbro appear to have been formed later than the rest of the region, as did the fault pattern located to the east.

POLAR URALS

The Polar Urals (Figure 1, 2, 14), being that section located north of latitude 64° N, provide a relatively complete geologic section with the most significant geologic feature being the Voykar ultramafic massif (Figure 14). These ultramafics, located between 64° N and 68° N, have a southeast strike which makes them coincident with the topographic expression of the Urals. Savel'yev and Savel'yev (1977) describe the massif as being 200 km long and divisible into three different rock series: (1) Khulga formation, the westernmost, is composed of garnet-zoisite amphiboles, (2) Payer formation of ultramafics, gabbro, and diabase, and (3) Lagorta formation of amphibolite and tonalite. The massif is described as an isoclinal fold overturned to the west or as an overthrust to the west (Lennykh et al., 1978; Bogdanov and Savel'yev, 1979) indicating that this structure is part of the western side of a suture zone. The ultramafic-gabbro ophiolite association of the Voykar zone has been described by Yazeva (1979) as a large marginal allochthon of ancient oceanic crust. To the east, the ophiolite association is replaced by a belt of tonalites, granodiorites and diorites that are comagmatic with Silurian-Devonian island-arc rocks that cap the section. A parallel (sheeted) dike complex, often indicative of ocean floor, is traceable for 150 km and varies in width from 1 to 3 km. The dikes, 0.5 to 1 m

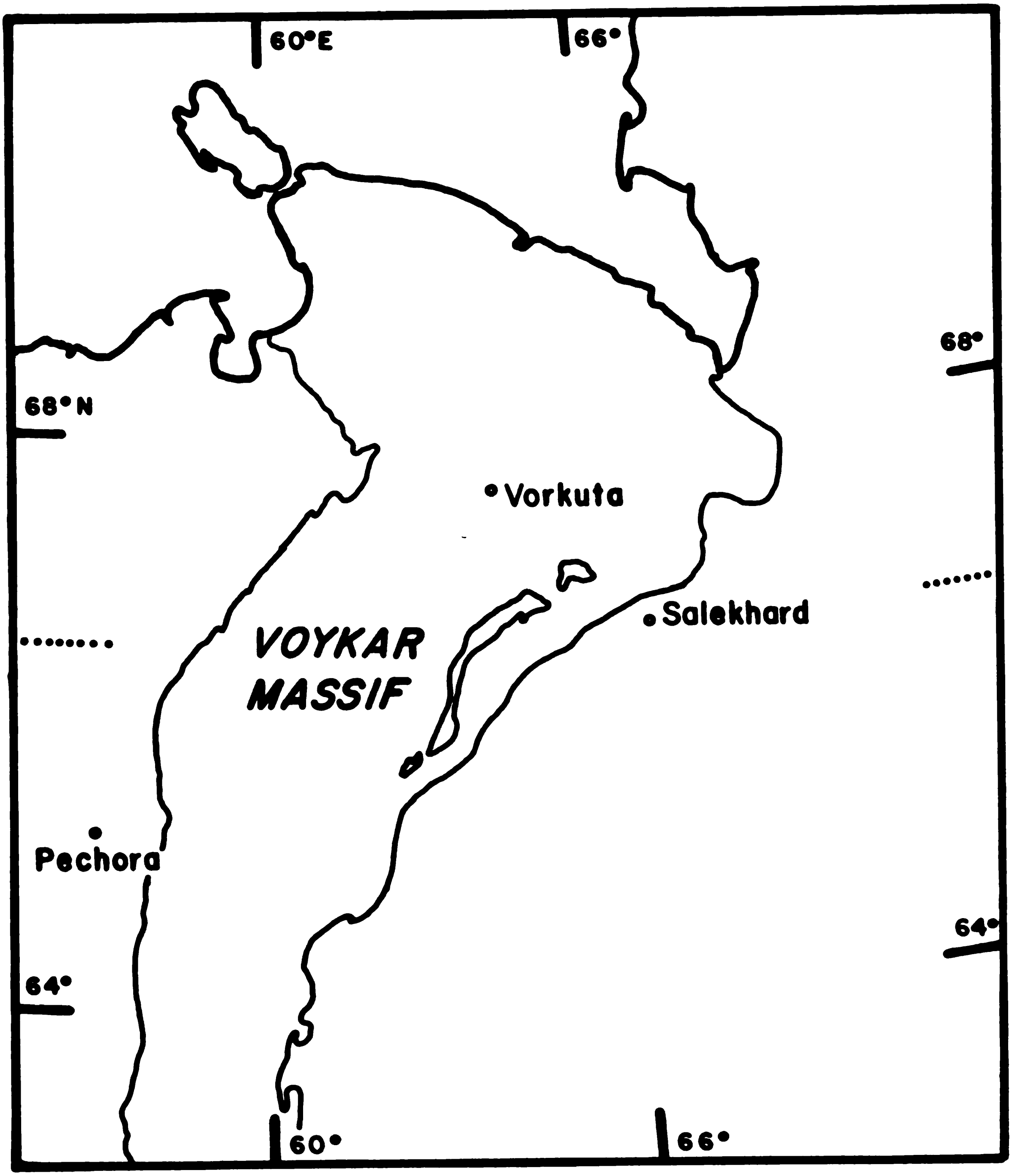


Figure 14. Map of the Polar Urals. Dotted line represents the Arctic Circle.

thick, are metamorphosed to greenschist epidote-actinolite facies. This metamorphism is attributed to compression at the time of formation of the oceanic crust (Yazeva, 1979). Located to the west of the ophiolite are Paleozoic flysch and pelagic formations crumpled into recumbent folds forming tectonic sheets (Bogdanov and Savel'yev, 1979). Detritus from the ophiolite first appears in Visean (C_1) sediments. Farther to the west lies undeformed Riphean basement and Paleozoic platform sediments. The west edge of the ophiolite has high pressure metamorphic rocks, however no volcanics are seen with the metamorphosed flysch and pelagic formations. The east contact of the ophiolite has quartz-tonalite and diorite which have K-Ar dates of 375 Ma (Middle Devonian). Farther east the diorites are an Upper Devonian volcanic and tuffogenic formation which Bogdanov and Savel'yev (1979) classify as an island-arc association. To the east of the Voykar massif lies the Lesser Urals structural facies zone, an Ordovician eugeosyncline, composed of clastic-volcanogenic and carbonate bodies of Ordovician, Silurian, and Devonian ages capped by Carboniferous clastics.

The Polar Urals may be interpreted as representing the western side of a zone of compression. No zone of collision is observed, yet the features of the Polar Urals suggest their origin is due to a subduction complex.

PALEOMAGNETICS

Appendix A lists all paleopole data available in the sources consulted (see Appendix A). Each paleopole was then examined to determine if it was consistent with other data points from the same plate and time period. Inconsistent poles and poles which could not be unambiguously assigned to a specific plate were deleted from the data set. Remaining pole positions were averaged and polar wandering curves were constructed.

As can be seen in Figures A-2 through A-6, despite the scatter, the continents did collide and did so within the time frame suggested by this study's model.

The polar wandering curves plotted in this study can not be directly compared with those of McElhinny (1973) because McElhinny used a longer time increment which necessarily would yield a smoother curve.

TECTONIC EVOLUTION

Figure 15 summarizes the tectonic evolution of the Uralian region. Paleomagnetic data shows the Russian, the Siberian, and the then-fragmented Kazakhstanian plates to be widely separated by oceanic regions during most of the Precambrian. Kazakhstania was formed during the Riphean when the Kokchetav and Ulutau continents collided, forming the western region of Kazakhstania. An incomplete suture of these blocks left a region floored by oceanic crust, which was later filled with sediments (Teniz Basin). During the Early and Middle Cambrian the Eastern margin of Kazakhstania collided with the Siberian plate. This collision signified the termination of southwestward subduction under the eastern margin of Kazakhstania. No subduction occurred along the northern margin of Kazakhstania hence the Kokchetav region did not collide with the Siberian continent.

The Bashkir, Zilair, and Uraltau terrane are floored by granitic continental without intervening oceanic crust. On this basis it may be concluded that the edge of the Russian platform extends eastward to the west edge of the Sakmara terrane. The Sakmara and Magnitogorsk terranes are floored by oceanic crust which was created during the Silurian period and later obducted onto the Russian platform. The driving mechanism for this obduction was a subduction complex located on the east side of the Sakmara terrane with subduction dipping westward beneath the Sakmara island-arc. This short-lived subduction zone created volcanics currently observed in the Sakmara terrane. Also contributing a horizontal component of motion was westward subduction under the Magnitogorsk island-arc. The Sakmara ultramafic was emplaced in the Late Devonian while the Krak massif and the rest of the Sakmara allochthon were emplaced during the final stages of closure of the ocean basin, no later than Early Carboniferous.

During the Eifelian (D_2) a brief period of subduction created andesite volcanism along the west margin of Kazakhstania. Also during this time andesite and basic volcanics of the Ishim terrane were generated as oceanic crust subducted eastward under Kazakhstania.

Shortly after the time of closure of the Sakmara back-arc basin, subduction ceased under the Magnitogorsk arc and initiated farther east, along the boundary between the Turgay and Ishim terranes. This west dipping subduction continued until Late Visean or Early Namurian time when subduction ended with final closure of the ocean basin. All volcanism had ended by the end of the Namurian.

By Late Carboniferous the Zilair terrane was a terrestrial region with carbonates being deposited between this terrane and the East Ural volcanic arc. This signifies a post-orogenic environment existed for the western part of the study area.

Shaley limestone deposition occurred in the Turgay terrane while sand and shale deposition took place in the Bashkir terrane. During the Permian period, all orogenic activity ceased and erosion of elevated land areas commenced.

Figure 15. Synthesis of reconstruction. Cartoons depict stages of development for the Riphean (R), Cambrian (C), Early Silurian (S_1), Early Devonian (D_1), Late Devonian (D_3), Early Carboniferous (C_1), Late Carboniferous (C_3) and Permian (P). Identification of terranes is as follows: R- Russian Platform; UB- Ufa-Bashkir; Z- Zilair; UT- Uraltau; S- Sakmara; M- Magnitogorsk; B- Bredy; EU- East Ural; T- Turgay; IS- Ishim; K- Kazakhstania; SP- Siberian Platform. Basement identification as follows:

vvvvvv - continental

/\/\/\ - oceanic

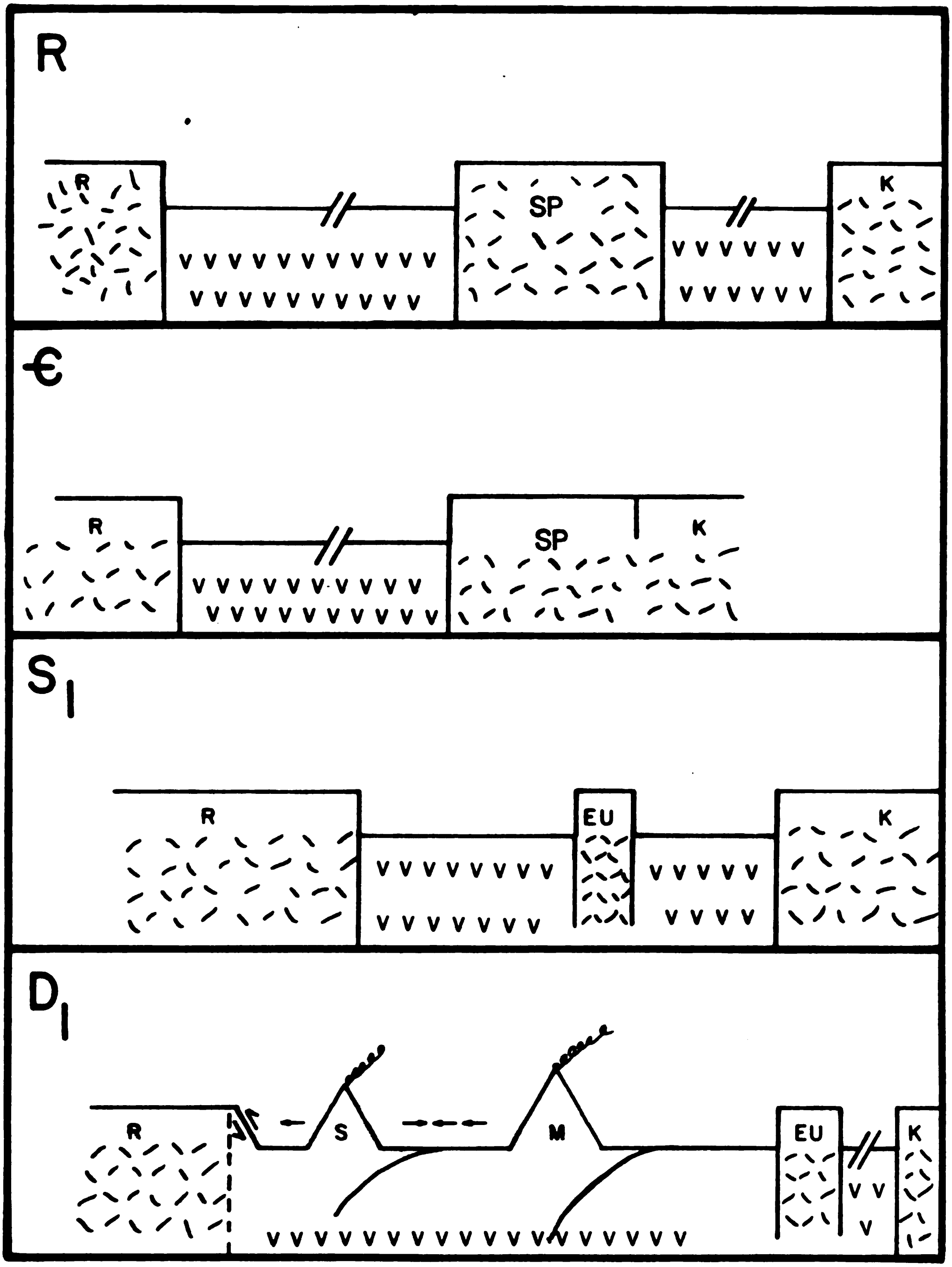
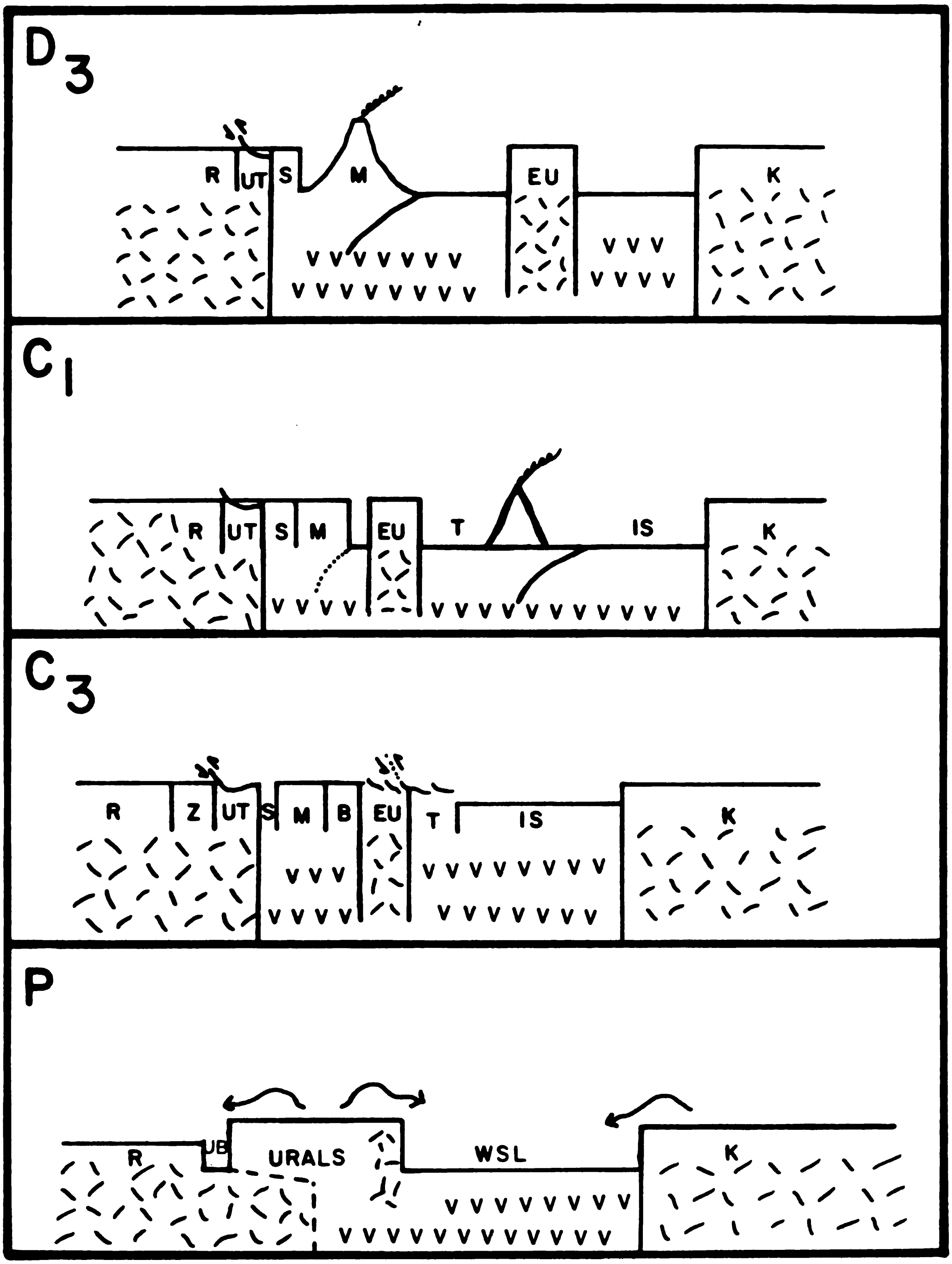


Figure 15.


D3
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DISCUSSION

The model proposed here differs from previous studies in several respects. Unlike Hamilton (1970), we suggest that Baltica and Siberia never fully collided and that oceanic crust continued to separate Baltica, Siberia and Kazakhstania when relative convergence ceased in the Middle Carboniferous, a date earlier than suggested by Hamilton.

One of the major differences between this study's model and the model of Hamilton (1970) lies in the amount and direction of subduction complexes utilized. This study suggests only westward dipping subduction with two jumps in location of the subduction. Hamilton (1970) uses several subduction complexes with direction of subduction flipping from east to west or west to east creating geometry that becomes unnecessarily complex. In some instances, these complexities are not confirmed, nor denied, by the observed geology and in other cases the suggested tectonics are possible, however a simple model is usually the preferred explanation. The question of feasibility is not easily solved. There is no definitive solution to the evolution of the Urals, only a most probable model. This study has proposed a model that is as simple as possible without omitting information present in the geologic record.

Additional subduction zones dipping various directions could be added since there is no evidence for or against their existence, however such is unsupported conjecture.

The model of Ruzhentsev and Samygin (1979) (see Previous Soviet Work) suggest subduction originating in Vendian time. This subduction created Middle Ordovician volcanism and Late Ordovician oceanic crustal spreading in the Sakmara zone. Several of these spreading centers exist in the model of Ruzhentsev and Samygin (1979) and they are described as spreading centers similar to those currently observed at mid-ocean ridges. These spreading centers and the expansive Sakmara trough are weak points in the model of Ruzhentsev and Samygin (1979). They have been included wherever spilites are observed and the size of the large Sakmara trough/spreading center is a matter of debate since direct measurements are not available. The amount of oceanic crustal material generated in the episode of Sakmara spreading is on the order of that generated in back-arc spreading rather than the larger scale normally observed in mid-ocean ridges. The Sakmara trough is required to be larger in the model of Ruzhentsev and Samygin (1979) to accommodate the model geometry. This study's model utilizes back-arc spreading as a mode of formation of oceanic crustal material, which puts no constraints on the size of the Sakmara basin.

Termination of activity in the Uralian region is dated by Ruzhentsev and Samygin (1979) as Late Devonian, an age not supported by the geologic data. It appears their sequencing is not unreasonable, however the time events originate and terminate is too early in the geologic record as evidenced by the composite stratigraphic columns presented in this study.

The model presented by this study agrees with the order of events published by Ziegler (1981), however this study's model shows Siberia joined with the Russian continent (Laurussia) by Namurian time rather than Late Permian as Ziegler (1981) suggests. It is noteworthy that the model presented by this study fits the geometry of previously published plate reconstructions, while providing a better analysis of the timing of events.

The use of translated articles from the Soviet literature has shown an interesting result in the course of this study. The model herein described is comparable in several ways to Soviet reconstructions although it has been generated without the use of many of the facilities and information available to the Soviet geologists. This is significant since it shows that enough of the necessary information is being translated from the Soviet literature into English in order that research can be conducted using translated articles.

APPENDIX A

APPENDIX A

Paleomagnetic Data

Paleomagnetic data collected for this study are included as Tables A-I, II, III. Data in Table A-II include all data collected, including data points not actually included in the final calculations. The information is arranged in ten columns.

Columns 1, 2, 3, and 4. Location and age of the samples. Column 1 gives the plate the sample is located on. Columns 3 and 4 are latitude and longitude. The plate abbreviations are as follows: R - Russian or Baltican plate, S - Siberian plate, K - Kazakhstanian plate, U - points located in the Urals, X - points on the Russian plate omitted from the final calculation, Z - omitted Siberian points, Q - omitted Kazakhstanian points. Column 2 is the time period (1 - 28), Precambrian through Cretaceous, listed in Figure A-I.

Columns 5 and 6. The declination of the sample is given in column 5 and the inclination in column 6.

Column 7 is the paleopole as determined by the original author, listed as northern hemisphere coordinates.

Column 8 gives the number of sites and the number of samples (site,sample) used for each determination by the original author. One or both of these numbers may be omitted if this information was not available.

Column 9 gives Fisher's circle of confidence α_{95} ($\underline{P}$=0.05).

Column 10 is the reference. Those numbers with a / (i.e., 10/144) are data available in McElhinny, Irving and the Catalogue of Paleomagnetic Directions and Poles (1972, 1975). References with a ; are taken from the Catalogue and are not listed by McElhinny or Irving.

Table A-III contains the data in Table A-II sorted by time period and listed according to plate. Note column 1 is time period and the plate is not given for each individual data point. Data listed in this table was used to calculate the paleopoles of each plate.

Table A-IV is the program used to calculate the average paleopole for each plate.

Table A-V is the program used to print a sort of the full paleomagnetic data file.

Figure A-I. Paleomagnetic time scale. Absolute ages taken from van Eysinga (1978). Paleomag index # is the assigned number used in the paleomagnetic pole program.

peroid		paleomag index #	Ma
Cretaceous	L	28	88-65
	M	27	100
	E	26	141
Jurassic	L	25	160
	M	24	174
	E	23	195
Triassic	L	22	212
	M	21	222
	E	20	230
Permian	L	19	245
	M	18	251
	E	17	280
Carboniferous	L	16	290
	M	15	315
	E	14	345
Devonian	L	13	360
	M	12	370
	E	11	395
Silurian	L	10	410
	M	09	423
	E	08	435
Ordovician	L	07	450
	M	06	475
	E	05	500
Cambrian	L	04	515
	M	03	540
	E	02	570
Precambrian		01	570+

Figure A-I.

Table A-I. Paleopole Positions. Pole positions plotted in Figures A-2,3,4 for Baltican, Siberian, and Kazakhstanian plates.

KAZAKHSTANIA

Time	Pole Latitude °N	Pole Longitude °E
12	42.1	199.8
13	55.8	194.1
14	68.9	202.9
15	66.5	194.9
16	64.5	193.7
17	58.3	174.7
18	58.3	174.2
19	55.0	166.1
20	55.6	193.5*
21	73.5	276.6
28	61.7	214.5

SIBERIA

Time	Pole Latitude °N	Pole Longitude °E
1	-2.0	124.7
2	21.3	157.2
3	30.3	340.4
4	34.6	308.9
5	41.8	309.5
6	-19.6	134.5
7	-22.0	124.8
8	-19.6	100.8
10	-10.0	70.3
11	34.2	148.5
12	31.1	163.5
13	25.5	158.2
14	46.9	8.1
15	8.2	145.1
16	41.1	151.1
17	35.1	177.7
18	47.3	150.6
19	30.7	139.5
20	56.0	146.8
21	19.6	297.7
24	21.7	162.5
28	73.5	17.9

RUSSIA

Time	Pole Latitude °N	Pole Longitude °E
1	51.3	211.5
3	3.5	-17.9
5	36.8	147.8
6	28.7	3.4
12	32.7	159.1
13	28.5	154.8
14	40.8	162.2
15	35.3	163.9
16	39.2	137.0
17	28.0	162.6
19	36.5	169.9
20	52.6	138.9
21	43.6	139.8

* = Pole inverted 180°.

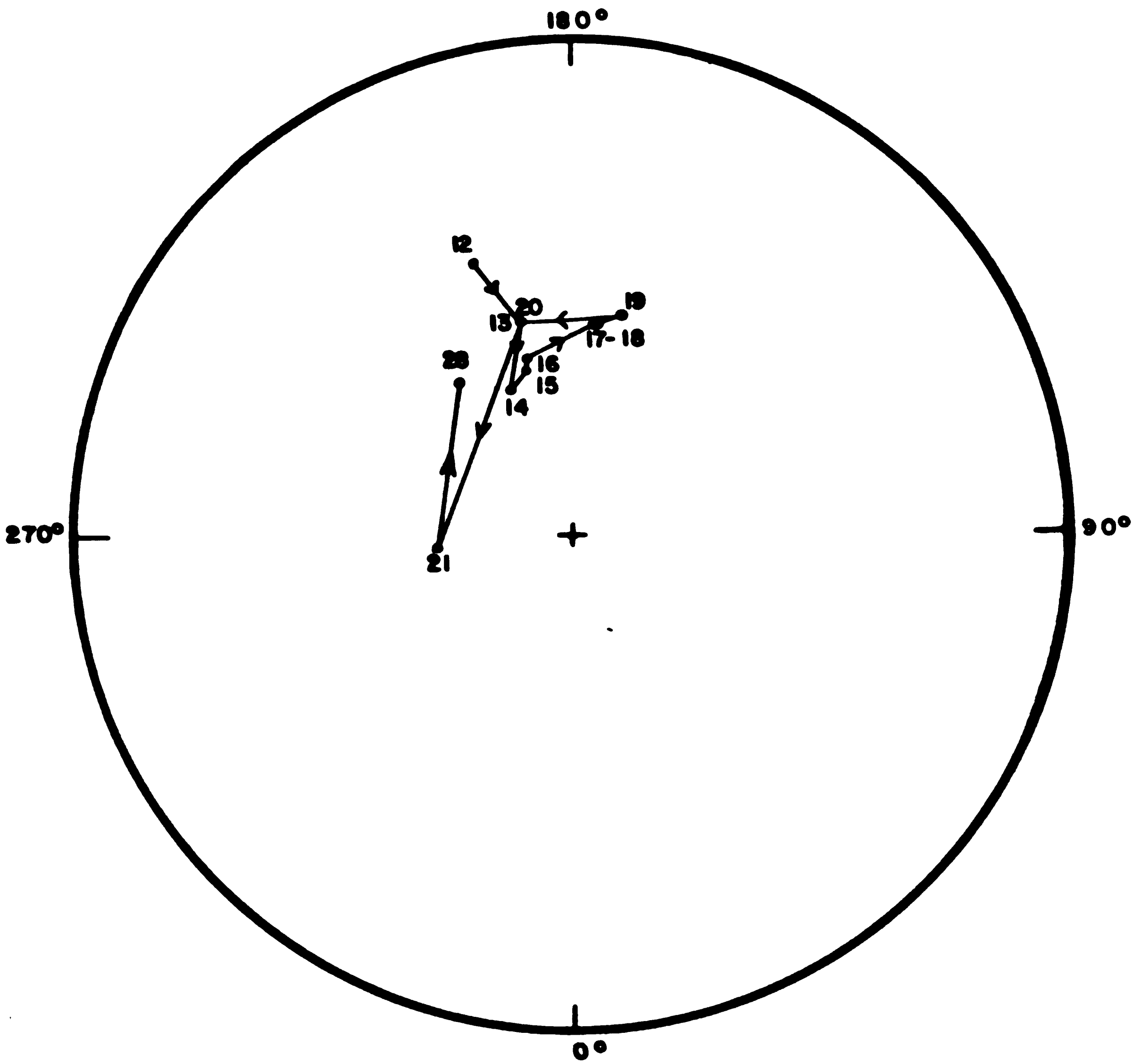

Figure A-2. Polar-wandering curve for Kazakhstania. Polar projection used. Numbers are representative of time periods as listed in Figure A-1.

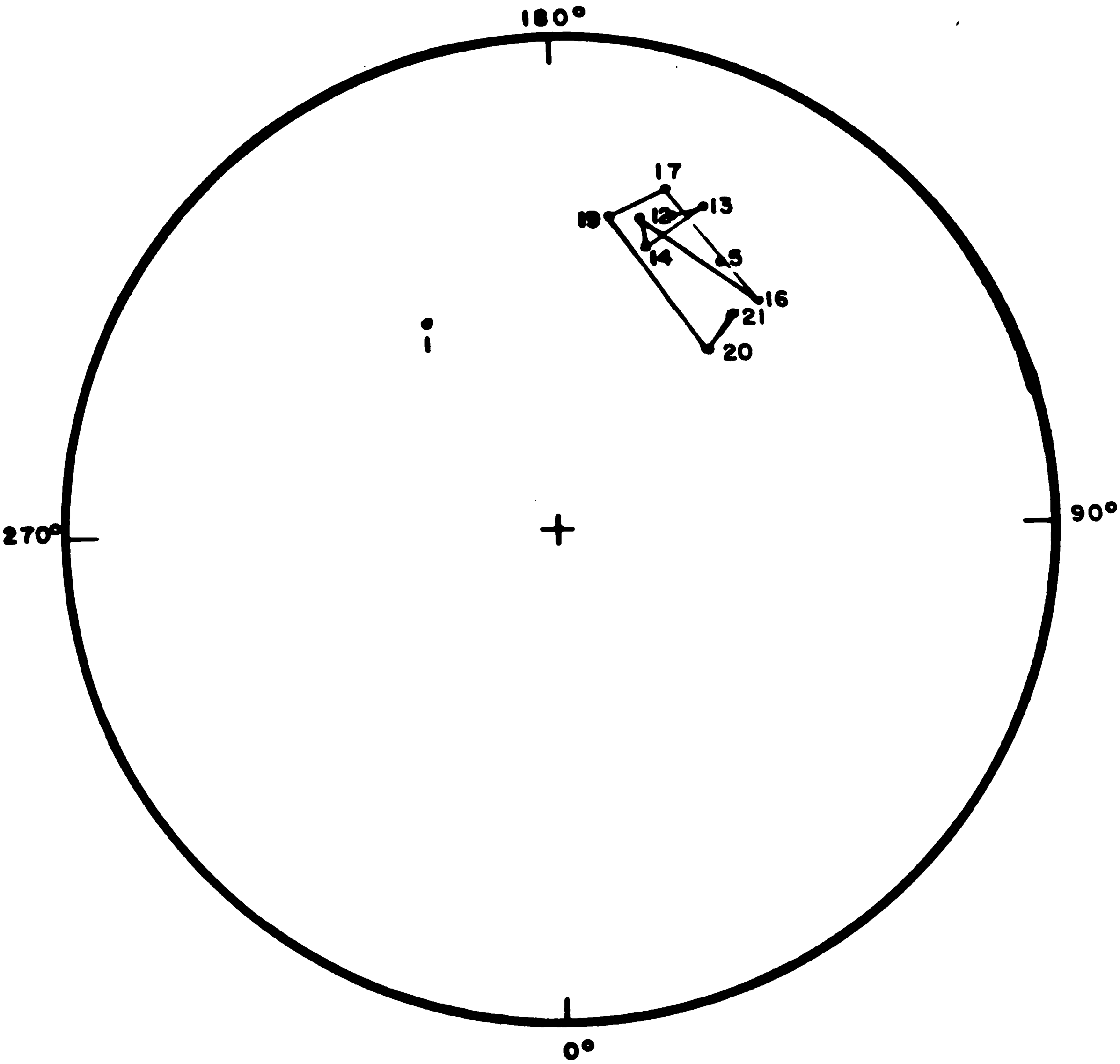

Figure A-3. Polar-wandering curve for Russia. Symbols as in Figure A-2.

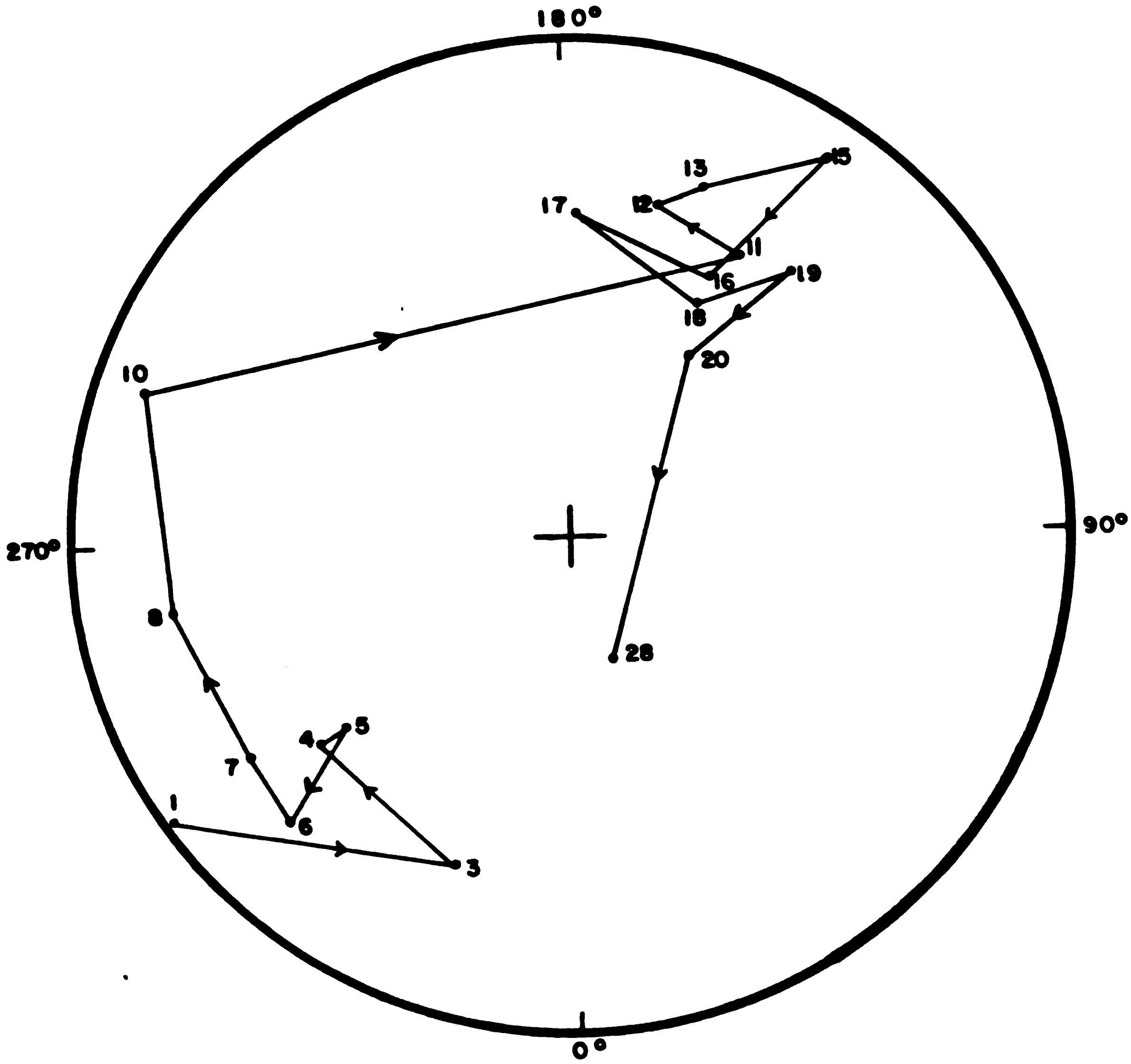

Figure A-4. Polar-wandering curve for Siberia. Symbols as in Figure A-2.

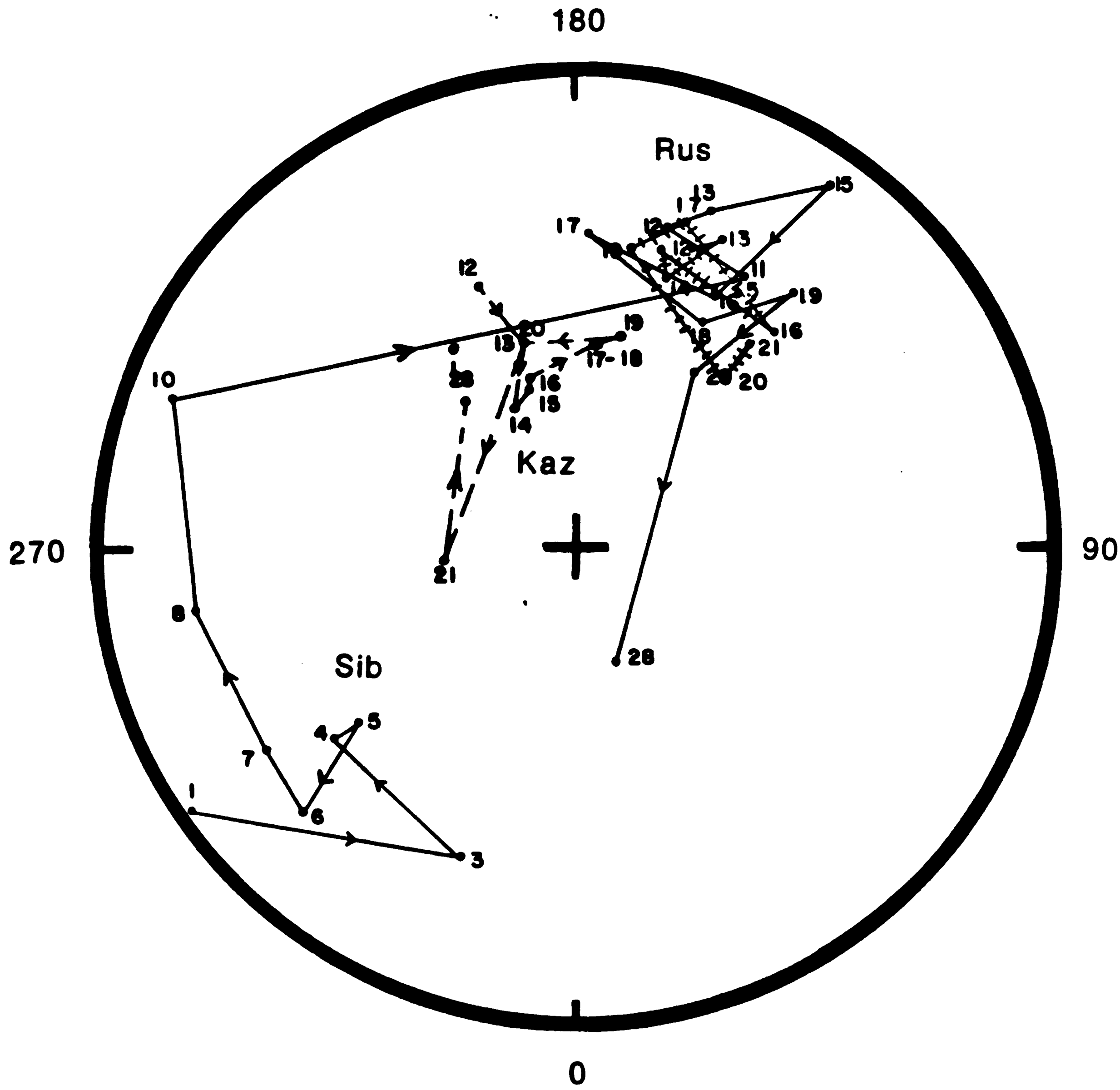

Figure A-5. Polar wandering curves for Kazakhstania, Russia, and Siberia superimposed.

Table A-II. Paleomagnetic data file. Complete file, unsorted, including all data points gathered. See Appendix A text for meaning of symbols.

Table A-II.

R 20	59	50	222	-19	53,44			2/32
R 19	59	51	38	57	52,176		10	2/33
R 19	59	51	211	-38	52,176		10	2/33
R 19	58	56	221	-40	45,178		15	2/35
R 05	60	30	38	41	42,169		18	2/38
R 05	60	30	211	-35	42,169		18	2/38
S 20	66	88	90	71	48,148	6,54		3/31
S 20	67	89	62	76	65,156	4,26		3/32
S 16	72	102	295	-68	40,150	,388	5	3/55
U 09	67	66	89	38	16,140	,6		3/69
R 06	51	26	255	58	21,27	2,8		3/70
R 06	51	26	140	75	28,46	1,6		3/71
R 13	59	31	221	-12	34,158		10	4/26
R 13	57	31	34	10	31,164		10	4/27
R 13	60	33	221	-16	28,159		10	4/28
R 20	48	38	39	57	60,135	,26		5/23
U 20	48	47	42	56	57,161	,52		5/24
U 20	49	52	45	46	49,158	,14		5/25
R 20	53	52	220	-51	54,164	,9		5/26
S 20	87	92	92	80	80,133	,92		5/28
S 20	63	114	179	87	59,114			5/29
S 21	71	101	286	-59	32,163	,31		5/30
S 21	71	101	117	64	35/150	,34		5/31
S 21	71	101	303	-64	34,146	,25		5/32
S 21	75	108	130	68	40,127	,29		5/33
R 19	61	46	42	48	48,165	,49		5/38
R 19	59	51	42	48	49,169	,34		5/39
R 19	53	52	46	46	48,162	,35		5/40
R 19	54	52	222	-38	45,171	,19		5/41
R 19	61	45	220	-35	41,172	,37		5/42
R 19	57	54	226	-44	45,167	35		5/43
R 19	57	55	229	-44	44,167	,15		5/44
R 19	56	55	228	-40	43,168	,31		5/45
R 17	48	38	225	-9	33,161	,34		5/46
R 16	48	38	218	-15	38,168	,76		5/48
R 16	48	38	209	-8	39,179	,48		5/49
R 14	59	34	38	38	43,162	,40		5/50
R 14	59	34	41	29	37,162	,18		5/51
X 14	58	34	78	25	17,127	,17		5/52
U 14	54	57	243	-30	22,150	,10		5/53
S 14	53	81	142	87	48,98			5/54
S 14	55	80	100	50	20,153			5/55
S 14	53	81	82	78	49,129			5/56
S 14	55	80	82	70	41,141			5/57
S 14	54	82	103	45	12,156			5/58
S 14	54	82	120	84	46,110			5/59
S 14	54	81	121	84	46,110			5/60
S 13	56	83	102	53	23,154			5/67
S 13	55	85	113	51	15,150			5/68
S 13	56	83	103	61	28,147			5/69
S 12	56	83	87	53	24,157			5/70

Table A-II. (cont'd)

S 12	55	85	104	65	30,146			5/71
S 12	56	83	98	59	28,152			5/72
S 12	56	83	285	-56	23,150	,28	10	5/73
S 12	56	83	89	55	29,163			5/74
S 12	55	85	86	50	28,168			5/75
S 11	56	83	88	53	32,162			5/76
S 11	55	85	86	66	39,154			5/77
S 12	56	98	311	27	28,155			5/78
S 12	56	98	115	4	28,155			5/78
U 06	54	57	253	-27	21,152	,60		5/79
S 06	60	118	352	16	22,302	,87	4	5/80
S 04	61	116	1	16	37,296	,47	8	5/84
R 03	49	25	233	51	2,344			5/85
K 12	48	74	218	-23	43,201	,22		6/60
U 10	67	66	85	44	22,141		21	6/65
S 11	56	83	91	51	25,163			7/42
S 01	58	95	6	-28	17,167			7/56
S 01	59	92	12	12	35,257	,23		7/57
S 28	56	92	330	72	74,18	,83		8/45
S 24	76	111	123	49	22,162			8/55
Z 21	76	111	168	18	4,303	,98		8/70
Z 20	76	111	161	39	9,129	,160		8/76
R 20	49	38	42	46	51,146		18	8/77
S 19	76	111	149	51	19,139	,60		8/78
R 19	55	53	40	37	44,176		13	8/82
R 16	56	38	212	-21	38,176			8/111
R 19	60	45	222	-43	45,167	5,81		9/69
R 19	59	50	228	-41	42,165	2,15		9/70
R 19	55	49	215	-44	51,178	2,23		9/71
R 19	54	53	227	-39	42,167	4,44		9/72
R 19	57	54	233	-42	40,163	3,54		9/73
R 19	58	56	230	-44	42,167	2,12		9/74
R 19	55	55	231	-39	40,165	2,33		9/75
S 17	53	82	264	-64	37,155		4	9/85
R 17	49	38	223	-20	37,161	3,151		9/86
R 17	48	38	219	-19	41,165	3,82		9/87
R 16	48	38	213	-10	39,174	4,218		9/92
R 16	56	39	217	-31	42,168	3,104		9/93
R 16	48	38	207	-8	50,182		3	9/94
X 16	48	41	212	20	25,186		8	9/95
K 16	52	63	200	-47	59,198		2	9/96
G 15	51	68	231	-52	48,161		5	9/99
U 15	56	62	247	-27	22,160		6	9/100
R 15	56	34	225	-21	33,158		4	9/101
R 15	55	39	220	-16	34,170		7	9/102
R 15	55	38	232	-18	29,155		5	9/103
R 15	54	42	224	-13	31,168		6	9/104
U 14	56	62	190	11	28,229		6	9/109
U 14	55	63	209	-30	45,199		9	9/110
R 14	60	34	217	-44	47,160		4	9/111

Table A-II. (cont'd)

R 14	59	33	220	-40	41,158		6	9/112
R 14	61	37	226	-48	46,152		4	9/113
S 14	66	89	284	-66	39,146		7	9/114
U 14	52	58	250	-20	20,163		10	9/115
U 14	53	57	257	-27	19,147		8	9/116
K 28	41	73	18	32	64,182	,13	20	10/53
S 21	56	63	66	59	44,142	18,	9	10/93
S 19	54	87	102	39	6,153	,11	11	10/99
S 19	54	87	108	42	10,159	,7	21	10/100
S 17	54	88	306	-42	2,137	,13	17	10/103
S 15	54	88	296	-41	10,146	,20	14	10/116
S 14	54	88	302	-24	7,314	,12	26	10/117
S 14	51	84	282	-31	3,160	,41	10	10/118
S 14	54	88	274	-40	18,162	,9	28	10/121
S 14	54	92	286	-36	7,158	,19	14	10/122
S 14	54	91	101	72	38,134	7,180	13	10/123
S 13	54	92	295	-66	25,134	,126	9	10/124
S 13	55	90	299	-46	8,147	,16	14	10/125
S 11	56	93	84	56	31,154			10/127
S 11	56	93	268	-47	31,154			10/127
S 11	55	95	125	53	29,166			10/128
S 11	55	95	282	-42	29,166			10/128
S 07	57	103	164	23	20,300	,133	4	10/131
S 07	58	108	162	10	25,308	,78	6	10/132
S 07	60	118	171	17	21,308	,48	4	10/133
S 06	58	108	159	12	24,311	,20	13	10/134
S 06	60	118	165	14	22,314	,27	4	10/135
S 06	58	108	162	14	23,308	,31	9	10/136
S 06	60	118	166	4	27,314	,20	13	10/137
S 05	57	107	164	-19	41,308	,22	13	10/138
S 05	57	104	160	-23	42,311	,19	12	10/139
S 04	54	106	160	2	33,310	,35	12	10/141
S 04	58	108	171	-8	36,299	,39	7	10/142
S 04	57	107	165	-17	41,307	,39	8	10/143
S 04	54	102	162	-13	41,306	,28	8	10/144
S 04	54	105	158	-3	34,312	17,202		10/145
S 01	59	98	132	24	10,142	,9	14	10/176
S 01	59	98	166	23	17,110	,99	4	10/177
S 01	59	98	160	18	18,116	,25	16	10/178
S 01	59	98	163	8	25,115	,35	11	10/179
S 01	58	98	170	22	20,106	,38	10	10/180
S 01	59	98	174	20	20,102	,77	7	10/181
S 01	59	98	178	31	13,98	,24	15	10/182
R 01	61	35	344	46	54,240	,29	4	10/198
R 01	62	34	348	30	44,231	,57	4	10/199
K 21	42	74	173	-45	75,273	4,	8	13/38
K 19	52	68	225	-56	54,169			13/43
K 18	52	67	233	-56	51,160			13/44
K 18	44	70	204	-46	63,189			13/45
K 15	43	70	204	-46	63,189			13/55

Table A-II. (cont'd)

K 15	52	68	210	-57	65,180			13/56
K 15	51	68	202	-52	65,196			13/57
K 15	50	70	204	-53	65,193			13/58
K 15	48	68	206	-50	64,188			13/59
K 14	51	68	201	-53	67,198			13/60
K 14	50	70	196	-54	70,206			13/61
K 14	48	68	197	-51	69,202			13/62
R 01	62	35	35	38	48,236	,86	5	1;257
U 01	53	57	193	34	17,224	,16	8	1;281
S 01	66	89	336	34	40,288	,39	8	1;280
S 01	59	92	12	12	37,257	,22	18	1;282
S 01	59	85	155	10	-22,122	,83	8	1;277
S 01	58	95	163	27	-16,112	,78	14	1;278
S 01	55	98	141	90	-22,141	,23	10	1;284
U 02	56	57	50	-31	78,189	,191	17	2;80
S 03	68	88	317	34	-36,135	,27	9	2;94
S 03	67	87	305	34	-31,152	,58	6	2;95
S 02	66	89	281	-47	21,157	,35	6	2;84
S 04	59	107	167	-7	-34,122	,43	11	2;89
S 04	58	107	169	-6	-34,120	,52	8	2;90
S 04	58	107	163	-16	-38,128	,18	13	2;91
S 03	57	87	272	36	-19,170	,22	10	2;81
R 05	59	28	237	-34	33,137	,10	7	3;65
R 05	60	30	240	-39	34,135	,11	16	3;63
R 05	60	30	216	-35	42,162	,6	11	3;64
U 07	55	57	272	-20	8,141	,6	16	3;57
U 07	54	57	255	-26	20,151	,110	4	3;58
U 07	54	57	264	-7	7,150	,22	8	3;59
Z 05	58	97	157	-19	-19,120	,101	13	3;56
U 06	57	60	233	12	16,184	,134	11	3;60
S 06	58	106	156	14	-22,132	,33	8	3;61
Z 06	68	88	304	12	-18,148	,90	1	3;62
Z 05	67	88	311	17	-26,144	,28	6	3;67
Z 06	68	88	308	5	-19,144	,42	6	3;66
U 09	53	57	232	-35	38,166	,9	12	4;38
U 08	55	57	272	-20	8,141	,6	16	4;43
U 08	54	57	255	-26	20,151	,110	4	4;44
U 09	53	57	232	-35	38,166	,9	12	4;46
U 09	58	60	83	10	8,152	,241	13	4;47
U 08	54	57	264	-7	7,150	,22	8	4;45
S 08	67	88	42	45	41,210	,16	16	4;39
S 08	68	88	285	-50	23,152	,53	5	4;40
S 10	67	88	47	36	34,212	,21	9	4;41
S 10	68	88	302	-66	34,132	,16	10	4;42
R 12	59	34	225	-23	32,159	,8	5	5;90
U 16	53	58	220	-40	47.178	,40	2	5;100
U 18	57	57	225	-27	35,181	,126	8	5;92
U 13	55	58	243	-11	20,164	,35	18	5;91
U 11	59	80	83	10	8,152	,241	13	5;86
U 13	54	59	44	34	40,179	,80	9	5;89

Table A-II. (cont'd)

K 13	50	66	209	-42	56,193	,8	9	5;88
Q 12	52	68	294	-74	34,101	,78	6	5;94
Z 12	67	88	64	63	50,178	,22	5	5;97
Z 12	67	88	233	-46	38,203	,68	7	5;98
S 12	68	88	280	-67	40,147	,37	6	5;99
S 11	68	88	279	-55	29,156	,38	2	5;103
S 11	55	83	84	56	31,154	,500	3	5;101
S 12	56	84	101	59	27,151			5;23
S 13	56	94	103	57	21,151	,204	5	5;93
S 12	53	85	87	57	32,162	,162	5	5;96
Z 12	56	83	301	-60	19,136	,18	12	5;95
Z 11	52	84	115	26	4,-24	,23	10	5;102
R 14	61	37	226	-48	46,152	,13	4	6;185
R 14	59	34	40	40	41,158	,25	6	6;183
R 14	58	34	214	-44	49,164	,20	5	6;184
R 14	59	34	221	-43	45,156	,38	4	6;182
R 16	56	34	225	-21	33,158	,40	4	6;186
R 15	56	38	217	-32	42,167	,33	2	6;218
R 15	56	38	218	-31	42,168	,71		6;225
X 16	55	38	241	-7	20,150	,35	4	6;187
R 15	55	36	221	-14	32,166	,17	7	6;222
R 16	48	38	207	-8	40,-178	,73	3	6;179
R 17	49	38	40	23	41,163	,424	5	6;180
R 16	48	39	215	-11	38,170	,129	2	6;181
R 16	49	38	213	-23	44,171	,137	3	6;239
R 14	48	38	224	5	27,167	,25	13	6;207
R 14	48	38	211	-5	38,178	,42	10	6;206
X 14	48	38	200	35	21,98	,10	17	6;205
R 15	48	38	42	-15	23,171	,45		6;211
R 15	48	38	32	-12	24,182	,49		6;220
R 15	48	40	217	10	29,177	,45		6;217
R 15	48	38	223	-2	26,157	,20	11	6;215
R 15	48	40	215	15	26,182	,48		6;216
X 15	48	41	221	-6	36,195	,20	21	6;214
X 15	48	41	192	25	28,208	,9	11	6;213
U 14	55	62	209	-30	45,199	,19	10	6;209
U 14	53	63	235	10	16,184	,23	12	6;212
U 14	56	62	190	11	28,229	,20	6	6;210
U 14	58	57	257	-27	19,147	,13	8	6;189
Q 14	52	68	260	-74	48,114	,117	3	6;203
K 16	52	68	210	-57	65,180	,70		6;193
K 16	51	68	202	-52	65,196	,40		6;194
K 16	50	70	204	-53	65,193	,50		6;195
K 16	48	68	206	-50	64,188	,70		6;196
K 16	44	70	204	-46	63,189	,378		6;197
K 15	51	68	201	-53	67,196	,40		6;198
K 15	50	70	196	-54	70,206	,44		6;199
K 15	48	68	197	-51	69,202	,40		6;200
Z 16	54	88	159	42	-8,107	,16	18	6;226
S 14	54	88	270	-42	20,162	,30	11	6;223

Table A-II. (cont'd)

S 14	55	88	315	-42	-1,139	,14	14	6;111
S 15	55	88	290	-46	13,146	,18	10	6;224
S 14	54	81	109	71	34,132	,107	6	6;204
S 14	58	103	287	-85	53,121	,19	12	6;208
S 14	59	105	128	81	47,125	,61	10	6;221
R 17	49	38	40	23	41,163	,424	5	7;204
R 19	49	38	224	-23	39,159	,29		7;146
R 19	61	45	46	39	40,160	,8	7	7;189
R 19	54	52	43	46	49,167	,38	5	7;186
R 19	59	51	49	44	43,162	,29	11	7;187
R 19	55	53	40	37	45,173	,7	13	7;188
R 18	57	54	230	-37	39,167	,35	7	7;190
R 19	54	52	223	-39	44,169	,20	8	7;191
U 18	58	49	227	-27	34,170			7;157
R 19	49	52	37	50	52,152	,35	4	7;184
U 18	57	55	227	-43	45,170	,39		7;34
R 19	58	49	227	-23	32,172			7;156
U 17	57	55	224	-39	43,173	,51		7;37
U 19	53	55	39	59	61,152	,12	11	7;185
K 17	52	68	233	-56	51,160	,55		7,173
K 17	44	70	204	-46	63,189	,266		7;174
K 19	52	68	225	-56	54,169	,23		7;172
S 18	53	91	74	69	47,151	,62	12	7;183
S 19	68	88	290	56	26,146	,50	7	7;193
S 17	54	88	159	42	-8,107	,16	18	7;180
S 19	71	102	102	64	39,163	,747	9	7;194
R 21	48	38	41	42	49,152	,53	11	8;144
R 20	48	47	49	55	52,150	,48	5	8;149
R 20	49	52	46	42	48,153	,17	10	8;148
R 20	59	51	218	-45	50,174	,10	15	8;155
R 20	53	51	51	43	43,155	,4	19	8;141
R 21	53	55	77	54	35,158	,18	9	8;145
R 20	53	55	47	70	62,125	,42	5	8;142
R 20	53	55	55	50	45,152	,19	4	8;139
R 20	53	51	41	47	51,164	,10	15	8;140
S 20	58	62	63	60	48,147	,711	9	8;146
K 20	48	80	280	59	25,135	,21	8	8;156
Z 20	68	88	290	56	26,146	,50	7	8;134
S 20	64	112	86	83	61,142	,114	2	8;152
S 20	64	112	90	75	52,162	,11	7	8;153
S 20	63	112	103	80	54,145	,25	5	8;154
S 20	68	91	82	71	43,153	,36	6	8;151
S 20	70	96	102	75	53,146	,120	6	8,150
S 20	71	102	102	64	39,163	,747	9	8;143
S 20	63	107	120	83	52,125	,79	10	8;136
S 20	59	103	136	85	53,115	,65	4	8;137
S 21	75	108	287	-65	41,168	,22	5	8;147

Table A-III. Paleomagnetic data file. Data sorted by plate, time period. See Appendix A text for explanation of columns.

Table A-III.

Kazakhstania

12	48	74	218	-23	43,201	,22		6/60
13	50	66	209	-42	56,193	,8	9	5;88
14	51	68	201	-53	67,196			13/60
14	50	70	196	-54	70,206			13/61
14	48	68	197	-51	69,202			13/62
15	43	70	204	-46	63,189			13/55
15	52	68	210	-57	65,180			13/56
15	51	68	202	-52	65,196			13/57
15	50	70	204	-53	65,193			13/58
15	48	68	206	-50	64,188			13/59
15	51	68	201	-53	67,196	,40		6;198
15	50	70	196	-54	70,206	,44		6;199
15	48	68	197	-51	69,202	,40		6;200
16	52	63	200	-47	59,198		2	9/96
16	52	68	210	-57	65,180	,70		6;183
16	51	68	202	-52	65,196	,40		6;194
16	50	70	204	-53	65,193	,50		6;195
16	48	68	206	-50	64,188	,70		6;196
16	44	70	204	-46	63,189	,378		6;197
17	52	68	233	-56	51,160	,55		7,173
17	44	70	204	-46	63,189	,266		7;174
18	52	67	233	-56	51,160			13/44
18	44	70	204	-46	63,189			13/45
19	52	68	225	-56	54,168			13/43
19	52	68	225	-56	54,169	,23		7;172
20	48	80	280	59	25,135	,21	8	8;156
21	42	74	173	-45	75,273	4,	8	13/38
28	41	73	18	32	64,192	,13	20	10/53

Table A-III. (cont'd)
Siberia

1	58	95	6	-28	17,167			7/56
1	59	92	12	12	35,257	,23		7/57
1	59	98	132	24	10,142	,9	14	10/176
1	59	98	166	23	17,110	,99	4	10/177
1	59	98	160	18	18,116	,25	16	10/178
1	59	98	163	8	25,115	,35	11	10/179
1	59	98	170	22	20,106	,38	10	10/180
1	59	98	174	20	20,102	,77	7	10/181
1	59	98	178	31	13,98	,24	15	10/182
1	66	89	336	34	40,298	,39	8	1;280
1	59	92	12	12	37,257	,22	18	1;282
1	59	95	155	10	-22,122	,83	8	1;277
1	59	95	163	27	-16,112	,78	14	1;278
1	55	98	141	90	-22,141	,23	10	1;284
2	66	89	281	-47	21,157	,35	6	2;84
3	68	88	317	34	-36,135	,27	9	2;94
3	67	87	305	34	-31,152	,58	6	2;95
3	57	87	272	36	-19,170	,22	10	2;81
4	61	116	1	16	37,296	,47	8	5/84
4	54	106	160	2	33,310	,35	12	10/141
4	58	108	171	-8	36,299	,38	7	10/142
4	57	107	165	-17	41,307	,39	8	10/143
4	54	102	162	-13	41,306	,28	8	10/144
4	54	105	158	-3	34,312	17,202		10/145
4	59	107	167	-7	-34,122	,43	11	2;89
4	59	107	169	-6	-34,120	,52	8	2;90
4	59	107	163	-16	-38,128	,18	13	2;91
5	57	107	164	-19	41,308	,22	13	10/138
5	57	104	160	-23	42,311	,19	12	10/139
6	60	118	352	16	22,302	,87	4	5/80
6	58	108	159	12	24,311	,20	13	10/134
6	60	118	165	14	22,314	,27	4	10/135
6	58	108	162	14	23,308	,31	9	10/136
6	60	118	166	4	27,314	,20	13	10/137
6	58	106	156	14	-22,132	,33	8	3;61
7	57	103	164	23	20,300	,133	4	10/131
7	58	108	162	10	25,308	,78	6	10/132
7	60	118	171	17	21,308	,49	4	10/133
8	67	88	42	45	41,210	,16	16	4;39
8	68	88	285	-50	23,152	,53	5	4;40
10	67	88	47	36	34,212	,21	9	4;41
10	68	88	302	-66	34,132	,16	10	4;42
11	56	93	88	53	32,162			5/76
11	55	95	86	66	38,154			5/77
11	56	93	91	51	25,163			7/42
11	56	93	94	56	31,154			10/127
11	56	93	268	-47	31,154			10/127
11	55	85	125	53	29,166			10/128
11	55	85	282	-42	29,166			10/128
11	68	88	279	-55	29,156	,38	2	5;103
11	55	93	94	56	31,154	,500	3	5;101

Table A-III. (cont'd)

12	56	83	87	53	24,157			5/70
12	55	95	104	65	30,146			5/71
12	56	93	98	59	28,152			5/72
12	56	83	285	-56	23,150	,28	10	5/73
12	56	93	89	55	29,163			5/74
12	55	95	86	50	28,168			5/75
12	56	88	311	27	28,155			5/78
12	56	88	115	4	28,155			5/78
12	68	88	280	-67	40,147	,37	6	5;89
12	56	94	101	59	27,151			5;23
12	53	85	87	57	32,162	,162	5	5;96
13	56	93	102	53	23,154			5/67
13	55	85	113	51	15,150			5/68
13	56	83	103	81	28,147			5/69
13	54	82	295	-66	25,134	,126	9	10/124
13	55	80	299	-46	8,147	,16	14	10/125
13	56	94	103	57	21,151	,204	5	5;93
14	53	91	142	87	48,98			5/54
14	55	90	100	50	20,153			5/55
14	53	91	82	78	49,129			5/56
14	55	80	92	70	41,141			5/57
14	54	82	103	45	12,156			5/58
14	54	92	120	84	46,110			5/59
14	54	91	121	84	46,110			5/60
14	66	89	284	-66	39,146		7	8/114
14	54	88	302	-24	7,314	,12	26	10/117
14	51	84	292	-31	3,160	,41	10	10/118
14	54	88	274	-40	18,162	,9	28	10/121
14	54	82	286	-36	7,158	,19	14	10/122
14	54	91	101	72	38,134	7,180	13	10/123
14	54	88	270	-42	20,162	,30	11	6;223
14	55	88	315	-42	-1,139	,14	14	6;111
14	54	81	109	71	34,132	,107	6	6;204
14	58	103	287	-85	53,121	,19	12	6;208
14	59	105	128	81	47,125	,61	10	6;221
15	54	88	296	-41	10,146	,20	14	10/116
15	55	88	290	-46	13,146	,18	10	6;224
16	72	102	295	-68	40,150	,388	5	3/55
17	53	82	264	-64	37,155		4	9/85
17	54	88	306	-42	2,137	,13	17	10/103
17	54	88	159	42	-8,107	,16	18	7;180
18	53	81	74	69	47,151	,62	12	7;183
19	76	111	149	51	19,139	,60		8/78
19	54	87	102	38	6,153	,11	11	10/99
19	54	87	108	42	10,159	,7	21	10/100
19	68	88	290	56	26,146	,50	7	7;193
19	71	102	102	64	39,163	,747	9	7;194
20	66	88	90	71	48,148	6,54		3/31
20	67	89	62	76	65,156	4,26		3/32
20	67	92	92	80	60,133	,92		5/28

Table A-III. (cont'd)

20	63	114	179	87	59,114			5/29
20	58	62	63	60	48,147	,711	9	8;146
20	64	112	86	83	61,142	,114	2	8;152
20	64	112	90	75	52,162	,11	7	8;153
20	63	112	103	80	54,145	,25	5	8;154
20	68	91	82	71	43,153	,36	6	8;151
20	70	96	102	75	53,146	,120	6	8,150
20	71	102	102	64	38,163	,747	9	8;143
20	63	107	120	83	52,125	,79	10	8;136
20	59	103	136	85	53,115	,65	4	8;137
21	71	101	286	-59	32,163	,31		5/30
21	71	101	117	64	35/150	,34		5/31
21	71	101	303	-64	34,146	,25		5/32
21	75	108	130	68	40,127	,29		5/33
21	56	63	66	59	44,142	18,	9	10/93
21	75	108	287	-65	41,168	,22	5	8;147
24	76	111	123	49	22,162			8/55
28	56	92	330	72	74,18	,93		8/45

Table A-III. (cont'd)

Russia

1	61	35	344	46	54,240	,29	4	10/198
1	62	34	348	30	44,231	,57	4	10/199
1	62	35	35	38	49,236	,86	5	1;257
3	48	25	233	51	2,344			5/85
5	60	30	38	41	42,169		18	2/38
5	60	30	211	-35	42,169		18	2/38
5	58	28	237	-34	33,137	,10	7	3;65
5	60	30	240	-39	34,135	,11	16	3;63
5	60	30	216	-35	42,162	,8	11	3;64
6	51	26	255	58	21,27	2,8		3/70
6	51	26	140	75	28,46	1,6		3/71
12	59	34	225	-23	32,159	,8	5	5;90
13	59	31	221	-12	34,158		10	4/26
13	57	31	34	10	31,164		10	4/27
13	60	33	221	-16	28,159		10	4/28
14	59	34	38	38	43,162	,40		5/50
14	59	34	41	29	37,162	,18		5/51
14	60	34	217	-44	47,160		4	9/111
14	59	33	220	-40	41,158		6	9/112
14	61	37	226	-48	46,152		4	9/113
14	61	37	226	-48	46,152	,13	4	6;185
14	59	34	40	40	41,158	,25	6	6;183
14	59	34	214	-44	49,164	,20	5	6;184
14	59	34	221	-43	45,156	,38	4	6;182
14	48	38	224	5	27,167	,25	13	6;207
14	48	38	211	-5	38,178	,42	10	6;206
15	56	34	225	-21	33,158		4	9/101
15	55	39	220	-16	34,170		7	9/102
15	55	38	232	-18	29,155		5	9/103
15	54	42	224	-13	31,168		6	9/104
15	56	38	217	-32	42,167	,33	2	6;218
15	56	39	218	-31	42,168	,71		6;225
15	55	36	221	-14	32,166	,17	7	6;222
15	48	38	42	-15	23,171	,45		6;211
15	48	38	32	-12	24,182	,49		6;220
15	48	40	217	10	28,177	,45		6;217
15	48	38	223	-2	26,157	,20	11	6;215
15	48	40	215	15	26,182	,48		6;216
16	48	38	218	-15	38,168	,76		5/48
16	48	38	209	-8	39,179	,48		5/49
16	56	38	212	-21	38,176			8/111
16	48	38	213	-10	39,174	4,218		9/92
16	56	39	217	-31	42,168	3,104		9/93
16	48	38	207	-8	50,182		3	9/94
16	56	34	225	-21	33,158	,40	4	6;186
16	48	38	207	-8	40,-178	,73	3	6;179
16	48	39	215	-11	38,170	,129	2	6;181
16	49	38	213	-23	44,171	,137	3	6;239
17	48	38	225	-9	33,161	,34		5/46
17	49	38	223	-20	37,161	3,151		9/86
17	48	38	219	-18	41,165	3,82		9/87

Table A-III. (cont'd)

17	49	38	40	23	41,163	,424	5	6;180
17	48	38	40	23	41,163	,424	5	7;204
19	59	51	38	57	52,176		10	2/33
19	59	51	211	-38	52,176		10	2/33
18	58	56	221	-40	45,178		15	2/35
18	61	46	42	48	48,165	,49		5/38
18	59	51	42	48	49,169	,34		5/39
18	53	52	46	46	48,162	,35		5/40
18	54	52	222	-39	45,171	,18		5/41
18	61	45	220	-35	41,172	,37		5/42
18	57	54	226	-44	45,167	35		5/43
18	57	55	229	-44	44,167	,15		5/44
19	56	55	228	-40	43,168	,31		5/45
19	55	53	40	37	44,176		13	8/82
19	60	45	222	-43	45,167	5,81		9/69
18	59	50	228	-41	42,165	2,15		9/70
19	55	49	215	-44	51,178	2,23		9/71
18	54	53	227	-39	42,167	4,44		9/72
19	57	54	233	-42	40,163	3,54		9/73
19	58	56	230	-44	42,167	2,12		9/74
18	55	55	231	-39	40,165	2,33		9/75
19	49	38	224	-23	39,159	,29		7;146
19	61	45	46	39	40,160	,8	7	7;189
19	54	52	43	46	49,167	,38	5	7;186
19	59	51	49	44	43,162	,29	11	7;187
19	55	53	40	37	45,173	,7	13	7;188
18	57	54	230	-37	39,167	,35	7	7;190
19	54	52	223	-39	44,169	,20	8	7;191
19	48	52	37	50	52,152	,35	4	7;184
19	58	49	227	-23	32,172			7;158
20	59	50	222	-19	53,44			2/32
20	48	38	39	57	60,135	,26		5/23
20	53	52	220	-51	54,164	,9		5/26
20	49	38	42	46	51,146		18	8/77
20	48	47	49	55	52,150	,48	5	8;149
20	49	52	46	42	48,153	,17	10	8;148
20	59	51	218	-45	50,174	,10	15	8;155
20	53	51	51	43	43,155	,4	19	8;141
20	53	55	47	70	62,125	,42	5	8;142
20	53	55	55	50	45,152	,18	4	8;139
20	53	51	41	47	51,164	,10	15	8;140
21	48	38	41	42	49,152	,53	11	8;144
21	53	55	77	54	35,158	,18	9	8;145

Table A-IV. Paleomagnetic pole calculation. Program used to calculate average paleopole positions.

```
      PROGRAM KAZMAG (INPUT, OUTPUT, TAPE8)
C     EQUATIONS TAKEN FROM MCELHINNY, 1973; 24-25.
C     NPG IS A TIMEING COUNTER.
      INTEGER TIME
      REAL INC,LAT,LONG
      INTEGER DATA(999,6),NOTIME(28)
      PI=3.1415927
      PI2=PI/180.
      PI3=180./PI
      REWIND8
      I=0
30    I=I+1
      READ (8,20) (DATA(I,J),J=1,6)
       IF (EOF (8)) 5,30
20    FORMAT (A1,1X,I2,1X,I4,1X,I4,1X,I4,1X,I4)
C     FORMAT IS PLATE, TIME, LAT, LONG, DEC, INC.
5     N=I-1
      PRINT 160
160   FORMAT (* WHAT PLATE?*)
      READ 40, IPLATE
40    FORMAT(A1)
      NT=0
      TIME = 0
80    TIME = TIME + 1
C   SET EVERYTHING TO ZERO
      NPG=0
      SXL=0. $ SXM=0. $ SXN=0.
      SPL=0. $ SPM=0. $ SPN=0.
      PI=3.1415927
      DO 60 I=1,N
      IF (DATA(I,1).NE.IPLATE) GO TO 60
      IF (DATA(I,2) .NE. TIME) GO TO 60
      NPG = NPG + 1
      DEC=FLOAT(DATA(I,5))
      INC=FLOAT(DATA(I,6))
C     CALCULATE AVERAGE DEC AND INC.
      SXL=SXL+(COS(DEC*PI2)*COS(INC*PI2))
      SXM=SXM+(SIN(DEC*PI2)*COS(INC*PI2))
      SXN=SXN+SIN(INC*PI2)
      LONG = FLOAT(DATA(I,4))
      LAT = FLOAT(DATA(I,3))
C     CALCULATE AVERAGE LOCATION.
      SPM=SPM+(SIN(LONG*PI2)*COS(LAT*PI2))
      SPL=SPL+(COS(LONG*PI2)*COS(LAT*PI2))
      SPN=SPN+SIN(LAT*PI2)
```

```
80    CONTINUE
      IF (NPG.NE.0) GO TO 75
      NT=NT + 1
      NOTIME(NT)=TIME
      GO TO 150
75    XR = SQRT((SXL**2) + (SXM**2) + (SXN**2))
      SR=SQRT((SPL**2)+(SPM**2)+(SPN**2))
      XMDEC=ATAN2(SXM,SXL)*PI3
      IF(XMDEC.LT.0.) XMDEC=XMDEC+360.
      XALONG=ATAN2(SPM,SPL)*PI3
      XALAT=ASIN(SPN/SR)*PI3
      XMINC =(ASIN(SXN/XR)) * PI3
      PRINT 90, TIME,XMDEC,XMINC
90    FORMAT(* MEAN DECLINATION AND INCLINATION FOR TIME * ,I3, * ARE*
     +, 2(1X,F6.0))
      PRINT 100, TIME,XALAT,XALONG
100   FORMAT (* MEAN SITE LOCATION FOR TIME *,I3,* IS *,2(1X,F6.1))
C CALCULATE MEAN POLES FROM MEAN INC AND DEC
C
C     XP IS THE COLATITUDE.
      XP=ATAN(2./TAN(XMINC*PI2))
C     XMLMBA IS MEAN LAT, XPHI IS MEAN LONG.
      XMLMBA=ASIN((SIN(XALAT*PI2)*COS(XP))+(COS(XALAT*PI2)*SIN(XP)*
     +COS(XMDEC*PI2)))*PI3
      XBETA=ASIN((SIN(XP)*SIN(XMDEC*PI2))/COS(XMLMBA*PI2))*PI3
      IF(COS(XP).GE.SIN(XALAT*PI2)*SIN(XMLMBA*PI2)) GO TO 110
      XPHI = XALONG + 180. - XBETA
      GO TO 120
110    XPHI = XALONG + XBETA
120   PRINT 130, TIME, XMLMBA, XPHI
130   FORMAT( * MEAN PALEOPOLE FOR TIME * ,I2, * IS * ,F6.1,F6.1)
150   IF (TIME .GE. 28) GO TO 140
      GO TO 80
140   IF (NT.GT.0) PRINT 180,(NOTIME(J),J=1,NT)
180   FORMAT (//* NO DATA FOR TIMES *,28(1X,I2))
      STOP
      END
```

Table A-V. Data sort routine. Program used to print a sorted data list.

```
      PROGRAM JAYSORT (INPUT,OUTPUT,TAPE8)
      INTEGER DATA (999,10), NOTIME (28)
      INTEGER TIME
      REWIND8
      I=0
30    I=I+1
      READ (8,20) (DATA(I,J),J=1,10)
      IF (EOF (8)) 5,30
20    FORMAT (A1,1X,I2,1X,I4,1X,I4,1X,I4,1X,I4,4X,A10,A10,A10,A10)
      GO TO 30
5     N=I-1
      PRINT 160
160   FORMAT (* WHAT PLATE?*)
      READ 40,IPLATE
40     FORMAT(A1)
      NT=0
      TIME=0
80    TIME=TIME+1
      DO 60 I=1,N
      IF(TIME.GE.29) GO TO 50
      IF (DATA(I,1).NE.IPLATE) GO TO 60
      IF (DATA(I,2).NE. TIME) GO TO 60
      PRINT 150, (DATA(I,K),K=1,10)
150   FORMAT (A1,1X,I2,1X,I4,1X,I4,1X,I4,1X,I4,4X,A10,A10,A10,A10)
60    CONTINUE
      GO TO 80
50    CONTINUE
      STOP
      END
```

APPENDIX B

APPENDIX B

Glossary

Nizhn(yaya)(iye) - lower

Verkhyaya - upper

Melanocratonic - dark colored igneous rock rich in mafic minerals (50-60% mafic)

Olistostrome - Peyve (1973): what Soviet geologists call olistostrome, European and American geologists call melange

Externide - Smirnov (1971): miogeosynclinal area between East European Platform in the west and the Main Uralian Fault in the east. Includes Bashkir and Uraltau zone.

Internide - Smirnov (1971): eugeosynclinal, i.e., Western Magnitgorsk and East Uralian Trough.

Tension - Khvorova et al. (1975): subsidence

Compression - Khvorova et al. (1975): uplift

1st order - upwarps and downwarps

2nd order - anticlinoria and synclinoria

3rd order - anticlines and synclines

Phthanite - dull cryptocrystalline siliceous rock, i.e., silicified shale, schist and especially chert

Tributary - handedness measured facing downstream

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