Vol. 1

Himalaya

(Geological Aspects)

Edited by :

Prof. P.S. Saklani

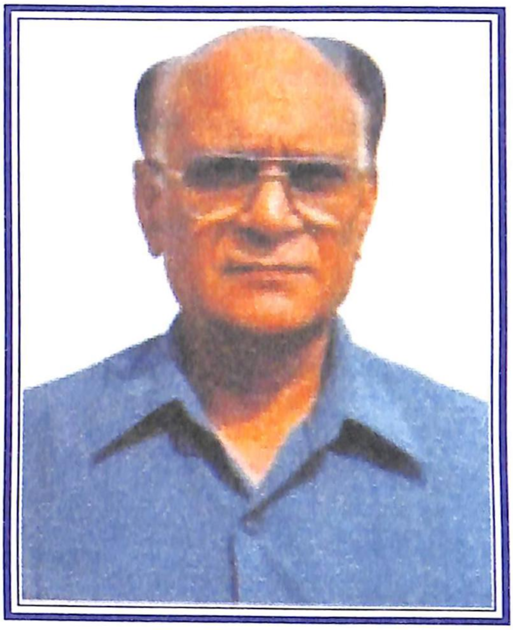
Himalaya

(Geological Aspects)

Edited by :

Prof. P.S. Saklani
Department of Geology,
University of Delhi

SSPH
SATISH SERIAL PUBLISHING HOUSE
403, Express Tower, Commercial Complex, Azadpur, Delhi - 110033 (INDIA)
Phone : 011-27672469, 27672852 Fax : 91-11-27672046
E-mail : ssp@ndf.vsnl.net.in, hkjain@satishserial.com
Website : www.satishserial.com



FOREWORD

The majestic Himalaya crowning the northern part of India has many important aspects of its geology, structure, tectonics and metamorphism. Because of its huge length and width its geological investigations are beyond the capacity of a single person. Therefore, it is always good to know the concepts and views from the Himalayan geologists who have been consistently, carrying out their researches for a number of years and with this background I brought out the edited volumes since 1978 and after. These volumes created a considerable interest amongst the Himalayan geologists in furtherence of their researches. Soon after these publications, they were out of stock and were not available in the market. I reclassified the research articles with possible revision and updation by the contributors and brought most of the contents in two volumes entitled, *Himalaya (Geological Aspects)* which are now on your hands. The *part one of the volumes* pertains to general geology and tectonics on regional basis in various sectors of the Himalaya. It is said that the geology of the Himalaya can be better understood if you also know the geology of the other surrounding ranges. Such types of research articles form the contents of the *first volume* The second volume mainly covers the structure and metamorphic aspects of the geographic subdivisions of the Himalaya. Many research papers focus on the structural/kinematic analysis of mesoscopic and microscopic structures. New research papers have also been included in both the volumes for making them more useful. It may be mentioned that some valuable contributors during the span of two decades are no more amongst us and therefore, their research papers are now of historical value. In fact, we are paying our tributes to the departed souls by publishing their contributions again. If we take a look of the geological research work of the present and past generations of geologists then we would observe that the interpretations about many of the geogical problems of the Himalaya have been either changed or modified. Many more such new interpretations would be available to us in future it is mainly due to advancement of science and technology. I hope these volumes would strengthen the foundation of the researches on the geology of the Himalaya in a significant way.

Prof. P.S. SAKLANI
Geology Department
University of Delhi.
Ex. Vice Chancellor
HNB Garhwal University
Ex. Chairman, Commission for Scientific &
Technical Terminology
(Govt. of India)

LIST OF CONTRIBUTORS

1. **Prof. S.V. Ruzhentsev**
   Prof. V.A. Shvolman
   Geological Institute of the
   U.S.S.R. Academy of Sciences
   Moscow, Russia.

2. **Prof. M.E. Brookfield**
   Guelph University, Geology Department
   Ontario, Canada

3. **Prof. D.P. Dhoundial**
   Formerly Director General
   Geological Survey of India,
   Kolkata, West Bengal

4. **Prof. J. Jaros**
   Head, Department of Geology
   Charles University
   Prague, Czechoslovakia

5. **Prof. J.G. Negi**
   Formerly Director
   Prof. P.K. Agarwal
   Prof. N.K. Thakur
   National Geophysical Research Institute
   Hyderabad, Andhra Pradesh

6. **Prof. Kewal K. Sharma**
   Formerly with Wadia Institute of
   Himalayan Geology
   Dehradun, Uttaranchal

7. **Prof. G. Fuchs**
   Formerly Director
   Geological Survey of Austria
   Vienna, Austria

8. **Prof. Takashi Nakata**
   Professor of Department of Geography
   Hiroshima University
   Japan

9. **Prof. Berthelsen**
   Formerly Chairman
   Geology Department
   Copenhagen University,
   Denmark

10. **Prof. Biq Ching Chang**
    Formerly Director
    Geological Survey of Taiwan
    Republic of China

11. **Prof. P.S. Saklani**
    Geology Department
    Delhi University

12. **Prof. M.N. Saxena**
    Formerly Geology Department
    Punjab University,
    Chandigarh

13. **Dr. A.K. Dubey**
    Prof. M.D. Bhat
    Sr. Scientist
    Wadia Institute
    of Himalayan Geology
    Dehradun, Uttranchal

14. **Prof. Chris T. Klootwijk**
    Research School of Earth Sciences
    Australian National University,
    Canberra, Australia

15. **Dr. L. Seeber**
    Dr. J. Armbruster
    Lamont Doherty
    Geological Observatory
    Prof. R. Quittmeyer
    Geology Department
    Columbia University
    Canada

16. **Prof. R.K. Verma**
Formerly Professor of Geophysics
Indian School of Mines
Dhanbad, Jharkhand

17. **Prof. S.K. Acharyya**
Formerly Director General
Geological Survey of India
Kolkata, West Bengal

18. **Prof. S.V. Srikantia**
Formerly Director
Geological Survey of India
Kolkata, West Bengal

19. **Prof. V. Divakara Rao**
National Geophysical Research Institute
Hyderabad, Andhra Pradesh

20. **Prof. S.K. Shah**
Formerly Head of the
Geology Department
University of Jammu
Jammu, J & K

21. **Prof. A.D. Gibbs**
Geology Department
Bedford College
University of London
London, U.K.

22. **Prof. I.C. Pande**
Formerly Head of the
Geology Department
Punjab University,
Chandigarh

23. **Prof. C.K. Sharma**
Formerly Chief Geologist Irrigation,
Hydrology & Meterology Department
Kathmandu, Nepal

24. **Prof. J.M. Remy**
Formerly University of Sciences
Montpellier, France

25. **Prof. B. Bordet**
Catholique University
Paris, France

26. **Prof. D. Krummenacher**
Geology Department
San Diego University
California, U.S.A.

Prof. F.A. Kingery
Westec Services
San Diego
California, U S.A.

Prof. A.M. Basett
Rue Daubeanton
Paris, France

Prof. H.F. Layne
San Fernando,
California, U.S.A.

27. **Prof. S. Sinha Roy**
Formerly Director
Geological Survey of India
Kolkata, West Bengal

28. **P.K. Das Gupta**
Professor of Geology

Prof. R. Mukherjee
Research Scholar
Kolkata University
West Bengal

Prof. A. Biswas
Lecturer in Geology
Bengal Engineering College
(Deemed University)
Kolkata, West Bengal

CONTENTS

TECTONICS AND STRUCTURE OF THE PAMIRS

S.V. Ruzhentsev, V.A. Shvolman

ABSTRACT

The Pamir is a northern part of the Northwestern Himalayan syntaxis. Structurally, it is a squeezed zone bent northward and is occupicd by the joint between the Kuu-Lun and Karakorum in the east and the Hindu-Kush in the west. The recent structure of the syntaxis resulted from Alpine movements, superimposed by earlier dislocations.

Important peculiarities of the Pamir structures show:

1. Change in the pattern of lineaments due to effects of transverse faults;
2. Degree of compression in the tectonic zones: with separated heterogenous zones;
3. Superposition of genetically different deformations.

Beside large nappes, there are transcurrent faults which, at depth, become thrusts.

INTRODUCTION

Two orogenic systems are distinguished within the Pamir boundaries. These are: the North Pamir, and the Central/South Pamir. Structure of the former was probably formed in the Triassic and that of the latter in the Cretaceous. Both of them later were deformed in Tertiary times. Actually, they represent gigantic sheets, which are thrust over one another. Their internal structures, however, differ with reference to their age, vergence and the time of predominant dislocations.

TECTONICS

The North Pamir is similar in many respects to South Tien-Shan and Kun-Lun. However, the South and Central Pamir are similar to the Karakorum and Central Afghanistan.

The North Pamir is separated from Tien-Shan by the Outer (or marginal) zone (Fig. 1) filled with thick Mesozoic and Cenozoic (molasse) series (Fig. 2).

The Kalaikhumb zone (an eugeosynclinal trough) resulted from splitting of the continental block (Cherner and Budanov, 1974). This zone exhibits the following lithological sequence:

1. Basalts intercalated with clays and clayey-siliceous shales; rarely associated, with limestone lenses. At times, exposures of serpentinized melange are also associated with them.
2. Varied facies of tuffs (acidic composition), volcanogenic sandstones, conglomerates and andesites/dacites (700-2000 m).
3. Olistostrome consisting of limestone blocks of Silurian and Devonian age, with a sandy-clayey matrix (1000-1500 m).

The olistostrome is tectonically overlain by miogeosynclinal deposits accumulated within the southern Kurgovat zone.

The neoautochthon is a thick series (upto 5000 m) of terrigenous and carbonate rocks.

The Kurgovat zone is distinguished by a wide distribution of Proterozoic gneisses, schists and quartzites, including the granite bodies. They are unconformably overlain by sandstones and phyllites limestones and dolomites subsequently followed by tuffs and lavas of liparitic composition. These are overlain by limestones sandstones and shales.

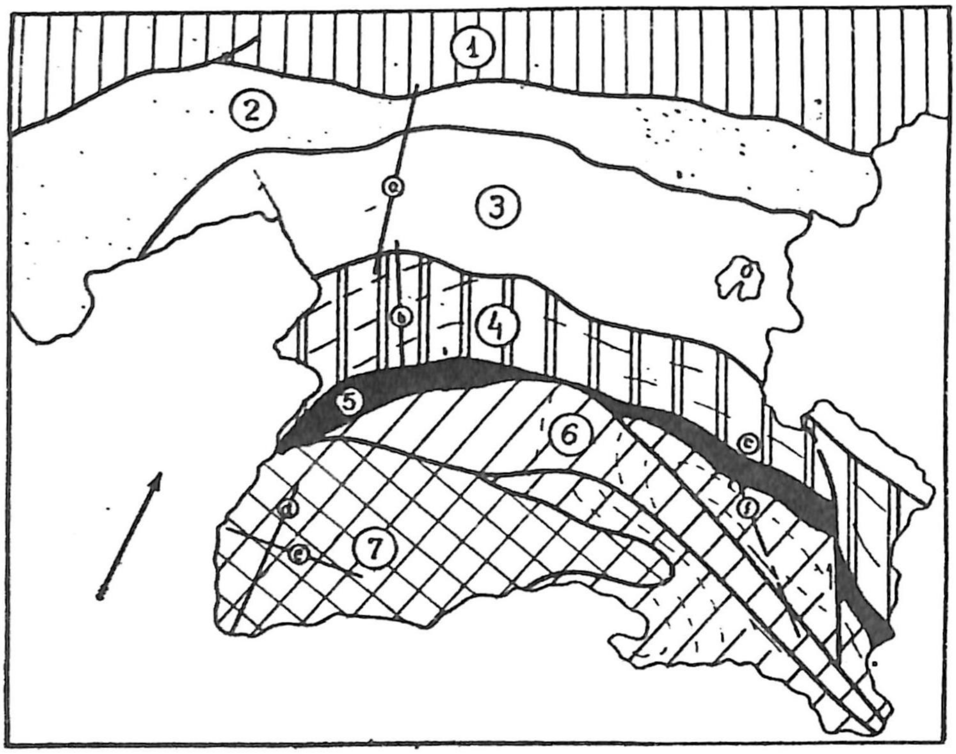


Fig. 1. Tectonic zonation of the Pamir.
1 – The Tien-Shan 2 – External zone, 3 – The North Pamir, 4 – The Central Pamir, 5 – Rushan-Pshart zone, 6 – The South-East Pamir, 7 – The South-West Pamir.

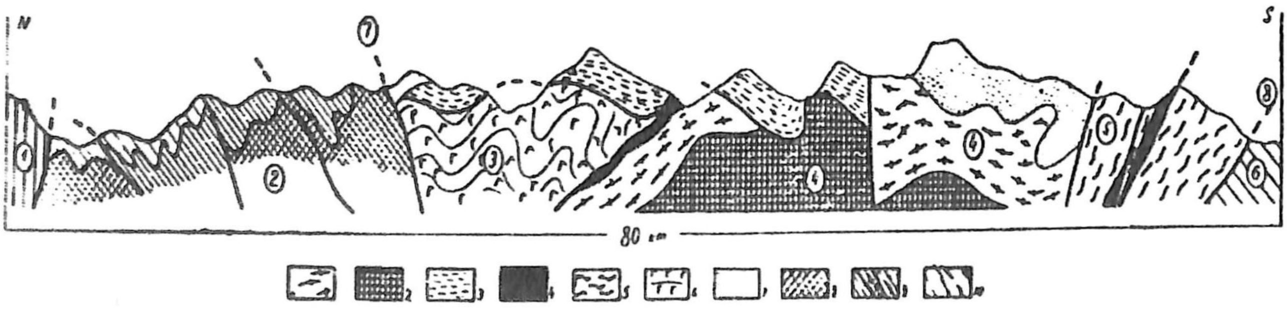


Fig. 2. Geological profile of the North Pamir (corresponds to the lIne "a" in Fig. 1).
- Gneiss, shales (PR1), 2- granites (PR1), 3- sandstones, limestones, tuffs, (V-C1), 4- ultrabasites, 5 - phyllites, schists, basalts (V-P), 6- basalts, andesites, dacites, and rafts, sandstones (C1), 7-sandstones, limestones, (C2-P), S—sandstones, limestones, marls (J), 9- sandstones, marls (K), 10- marls with gypsum, claystones, sandstones, conglomerates (p). Figures on the profile 1- Tien-Shan, 2- External zone, 3- Kalaikhumb zone, 4- Kurgovat zone, 5-Darvaz-Sarykol zone, 6 -The north Pamir, 7- Karakul overthrust, 8 -Tanymass thrust.

Karakul zone has not been studied extensively. Its Early and Middle Palaeozoic deposits are similar to the Kurgovat zone. The Late Palaeozoic sequence has different composition. Permian limestones, silt-stones and sandstones were replaced by limestones. The same zone is also represented by Permian volcano-plutonic association (rocks of intermediate and basic composition). The deposits are intruded by bodies of Triassic granites. This suggests that the Karakul volcanites were either formed on a sialic basement or sialic blocks were underthrust beneath them.

Darvaz-Sarykol zone includes several lithological units and constitutes different parts of a complex structure. The base of its western part is composed of green-slate series, associated with serpentinite bodies. In the east, the sequence begins with a thick series (2500 m) of trachybasalts, trachyliparites and keratophyres. This possibly indicates an initial rifting process in the continental plate.

Higher up, they are replaced by clayey shales, acid and intermediate effusives, sandstones and limestones. Carboniferous-Permian deposits are represented by shales, sandstones and diabases, which are several kilometers in thickness.

Assuming that the tectonic shifting of zones did not take place in the North Pamir the palaeotectonic profile would involve the northern part (the Kalaikhumb zone) which was characterized in the Early Carboniferous by a basin of the oceanic type. A system of "island arc-marginal basin" was formed here. The mini continent was situated to the south. One of its parts was stable (the Kurgovat zone). It is possible that these represent secondary extension zones. The Darvaz-Sarykol zone is considered as a newly-formed marginal basin with a crust of the suboceanic type.

The Alpine orogenic system includes the Central and South Pamir.

Central Pamir is confined to the Tanymass thrust and the Darvaz-Sarykol zone was over-thrust from the north. The northern part of the Central Pamir was geologically investigated by many workers (Pashkov, 1962; Karapetov, 1963; Kushlin, 1963; Droner and Andreeva, 1962; Ruzhentsev, 1971), Pre-Cambrian quartzites and marbles are conformably overlain by limestones, marbles, sandstones and claystones (600-800 m). They were possibly followed by thin and persistent limestones, sandstones and claystones (upto 3000 m), unconformably overlain by sandstones, limestones and marls (150-200m). These are replaced by sandstones, claystones and conglomerates (upto 2000 m), marls and limestones (800 m), red sandstones and claystones (upto 1500 m). The latter are unconformably overlain by limestones (20-400 m), conglomerates, andesites and tuffs (up to 300-400 m).

The southern part of the Central Pamir has a different lithological sequence. Pre-Cambrian rocks are overlain by sandstones and marls. Mesozoic and Cenozoic sequence, as a whole is similar to the one described above. However, the terrigenous series is absent, while the Palaeogene is represented by andesite and the tuffs, upto 500 m in thickness.

The Central Pamir is characterized by a nappe structure (Ruzhentsev, 1971). The sedimentary cover in the northern part of the zone was detached from its Pre-Cambrian basement, and formed gigantic allochthonous masses as a result of which Palaeozoic deposits overlie either on Mesozoic or Palaeogene layers in vast territories (Fig. 3).

Rushan-Pshart Zone lies to the south of the Central Pamir. Structurally, it is a system of sheets (Fig. 4), formed by varied lithofacies (Fig. 4). The base of the sequence is composed of sandy and clayey series (over 1000 m). The latter is overlain either by basalts and limestones (300 m), basalts, cherts, sandstones (2000 m) or cherts, limestones (200 m), basalts, cherts, limestones, sandstones (upto 2000 m), greywacke (700 m) and sandstone (K, 800 m). At places, they include ultrabasites and gabbro.

The plainspastic reconstructions (Pashkov and Shvolman, 1979) showed that the zone was a trough and its formation was related to the rifting of the continental plate.

South-West Pamir has a Pre-Cambrian basement. It is represented by the following sequence:

1. Goran series - biotite-plagioclase gneisses, quartzites, marbles.
2. Khorog series - amphibole, pyroxene-amphibole, garnet-biotite-amphibole gneisses, eclogites, garnet-amphiboles, pyroxene-garnet slates, ultrabasites (Cherner and Budanov, 1974; Budanova, 1973).
3. Shakhdarin series - plagioclase gneisses and marbles.
4. Alichur series—gneisses, migmatites and marbles.

The South-West Pamir is a dome with its core composed of the Goran series rocks. Its margins are respresented by the Shakhdarin and Alichur series .(Fig. 5). Mylonites, forming thick layers and marking subhorizontal surfaces of shears and overthrusts are widely distributed here. A rock-bed (upto 200-300 m) occurs at the base of the Khorog suite. The rocks of Goran and Shakhdarin series are similar, while those of the Khorog are different. The latter are typical "basalt" layers of the continental crust or the transitional zone-"basalt"-"granite" layers. (Belov et al., 1976).

The South-East Pamir is composed of a series of sedimentary rocks filling north-western end of a vast depression extending into the Karakorum. It has the following succession (Dronov find Leven, 1961; Ruzhentsev, 1968):

1. Sandstones, siltstones, claystones and thin interbeds of limestones (more than 1500 m);
2. Aphanitic and organogenic-clastic limestones, radiolarites siliceous limestones consist of basic lavas and tuffs (50-800 m); the aphanitic limestones are replaced by reef limestones;
3. Sandstones, siltstones, claystones (1500 m);
4. Organogenic-clastic, aphanitic-oolitic-limestones, marls and less frequently sandstones (upto 2000 m);
5. Variegated conglomerates, dacites, andesites, quartz porphyries, tuffs and sandstones, marls and limestones (upto 1000 m);
6. Sandstones and conglomerates (upto 600 m).

The deposits are intruded by a complex of granitoids of Mesozoic age.

Two types of deformations were established. The first was a system of large overthrusts, (Fig. 6). The second deformation is represented by right-side displacement of some blocks over a distance of 90-100 m.

At present, there is no uniform palinspastic scheme of the Pamir. However, it is evident that the Pamir was a system of troughs with oceanic or suboceanic type of crust separated by sialic blocks. The troughs were formed mainly due to subsequent rifting and separation of the continental plates. Within the North Pamir, this process started in the Early or Middle Palaeozoic and within the Alpine system in the Permian. The sialic blocks separating them remained stable. However, they were also subjected to crushing. As a result, the troughs were filled by thick terrigenous series formed frequently on Palaeozoic shelf deposits or directly on the crystalline basement.

STRUCTURE

Nappes and main thrusts: The structure of the Pamir is heterogenous. It includes dislocalions of different vergence. Their genesis and age reflect a complex history of evolution. Nappes and thrusts are present in all zones. Middle and Late Palaeozoic, Late Mesozoic and Alpine dislocations with different morphological dimensions have been established here. They are observed in the sedimentary cover.

Morphologically, the following types of nappes can be distinguished: (1) tectonic plates (more or less deformed), (2) nappe folds, (3) plates deformed into nappe folds. These occur in rocks of the basement and the cover.

Central Pamir: It is a system of antiforms and synforms. The former are autochthonous swells, while the latter are allochthouous outliers. Their correlation is most distinctly observed in the western part of the Central Pamir (Fig. 3).

The Vanch antiform, composed of Pre-Cambrian rocks, overlain by Cambrian, Ordovician and Silurian deposits, is exposed along the northern part of the region. The Yazgulem, synform consisting of Palaeozoic and Mesozoic/Cenozoic allochthonous series is exposed towards the south. Its eastern continuation is characterized by nappes (upper course of the Bartang river) which occur in numerous flat outliers. The Muzkol antiform lies in the south. Rocks of Pre-Cambrian, Triassic, Jurassic and Cretaceous age are exposd within its boundaries.

The autochthon consists of: (1) Pre-Cambrian/Lower Palaeozoic, (2) Triassic-Jurassic, and (3) Cretaceous/Palaeogene rocks which are seprated by shear surfaces.

1. Pre-Cambrian rocks exhibit deformation of two generations. 'Frequently, the folds are conjugated with gentle overthrusts. Two types of structure are observed. The first folds are longitudinal flexures, which stretch for tens of kilometers along the strike. The dislocations vary in amplitude from 20 to 30 km and are widely distributed over the territory of the Vanch antiform. The dislocations observed in the Muzkol antiform are predominantly associated with flow folds. The anticlines are isoclinal and occur in series of digitations. Their crests are sharp and undulated. The synclines are flattened and have angular curves. Amplitudes of both of them sometimes range upto 15-20 kin.

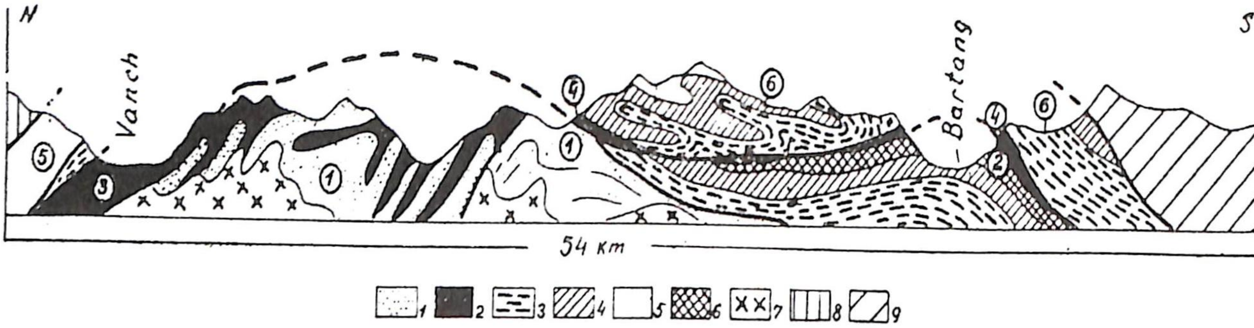


Fig. 3. Geological profile of the Central Pamir (corresponds to the line "b" in the Fig. 1).
1 - quartzites, marbles (Y-C), 2 - limestones, sandstones, shales (O-P), 3 - sandstones, claystones (T_3-J_2), 4 - marly limestones (J_{2-3}), 5 - sandstones, claystones (J_3-K_1), 6 - limestones, conglomerates, andesites and tuffs, sandstones (K_2-P). 7 - granitoids (P), 8 - The north Pamir, 9 - Rushan-Pshart zone.
Figures on the profile : 1 - autochthon (Vanch antiform), 2 - parautochthon (Muzkol antiform), 3 -roots of the Vanch nappe, 4 - Yazgulem nappe (synform).

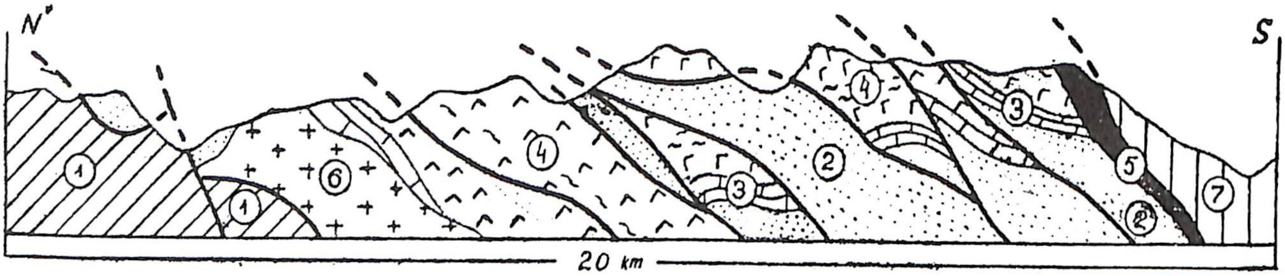


Fig. 4. Geological profile of the Rushan-Pshart zone (corresponds to the line "C" in Fig. 1). I -The Central Pamir. 2.6 - Rushan-Pshart zone: 2 - sandstones, claystones (C-P), 3 - limestones, cherts, basalts (Pa), 4 - basalts, cherts, sandstones, limestones (T-K), 5 - ultrabasites, 6 - granites, 7 - the South-West Pamir.

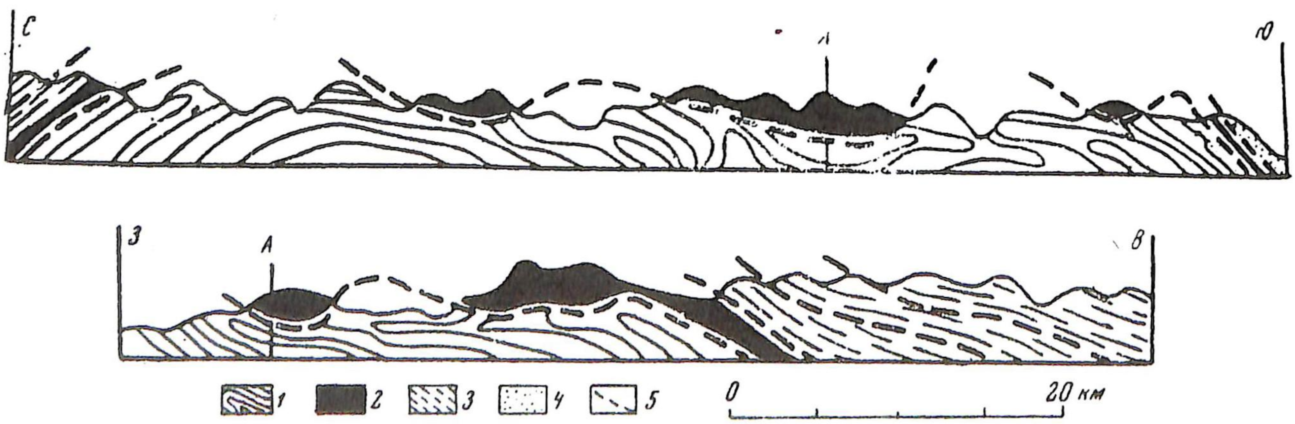


Fig. 5. Geological profile of the South=West Pamir (corresponds to the line "d" and "e" Fig. 1).
1- Goran series, 2 - Khorog series, 3 - Shakhdarian series, 4 - Upper Triassic rocks, 5 - Faulted mylonite beds.

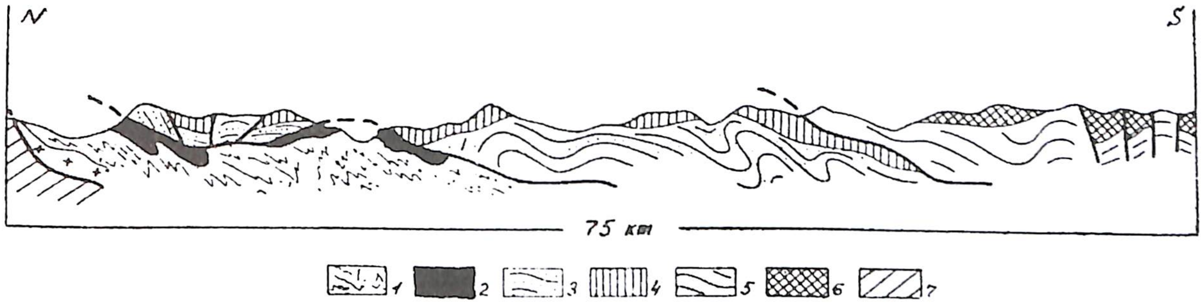


Fig. 6. Geological profile of the South-East Pamir (corresponds to line "f" in Fig. 1).
Lower plate: l- sandstones, clayslones, marls, cherts (C-T_3r), 2 - limestones, marls, sandstones (J_3-J_3c1); middle plate : 3—sandstones, claystones, limestones, cherts, basalts and tuffs (C_1-T_3r), 4—limestones, marls (J_3-J_3c1); upper plate: 5—sandstones, claystones, limestones (C-T_3r), 6—limestones, marls (J_2-J_3km), 7—Rushan-Pshart zone.

Later generations of folds are associated with steep dislocations, associated with narrow (3-6 km) zones. Dislocations, 100-200 m wide, with visible amplitude of 2-4 km are frequent. The isoclinal structures are complicated by their association with vertical upthrusts due to which the zones of isoclinal folds acquire the shape of a steep wedge. The deformations, folding intensity, shears with zones of steep structures are rather similar on the "Alpine lines" and hence have been regarded by us as belonging to root zones. Maximum reduction of the primary width of the autochthon is also noticed. Recumbent folds are well distributed within the Muzkol antiform boundaries.

2. Triassic and Jurassic rocks exposed around the territory of the Muzkol antiform exhibit a disorderly system of folds. Triassic/Jurassic beds are deformed into small upright and inclined folds with associated dislocations.
3. Cretaceous and Palaeogene deposits are also sheared at their basement. The stratification is in parallelism with the shear surface.

It may be aptly mentioned that processes of disharmonic stratification of sedimentary cover are generally typical of the Pamir. Growth of dimensions and intensity of dislocations down the sequence show that in the lower levels the main movements were active. The structures of parautochthon may be considered as reflection of deep-seated deformations.

Allochthon consists of several plates:

1. In western part of the Central Pamir (the Yazgulem synform), Triassic, Jurassic and Palaeogene deposits of the parautochthon are overlain by the Vanch nappe (Cambrian/ Ordovician, Devonian, Permian) and are distinguished as the Akbaital nappe in the eastern part of the Central Pamir.
2. The Yazgulem nappe is formed by Upper Triassic, Jurassic, Cretaceous and Palaeogene deposits. In the east it is sub-divided into two isolated plates. The Tuzbel plate is composed of Triassic, Jurassic and Cretaceous beds, while the rocks of the Chabarang plate are Cretaceous-Palaeogene.

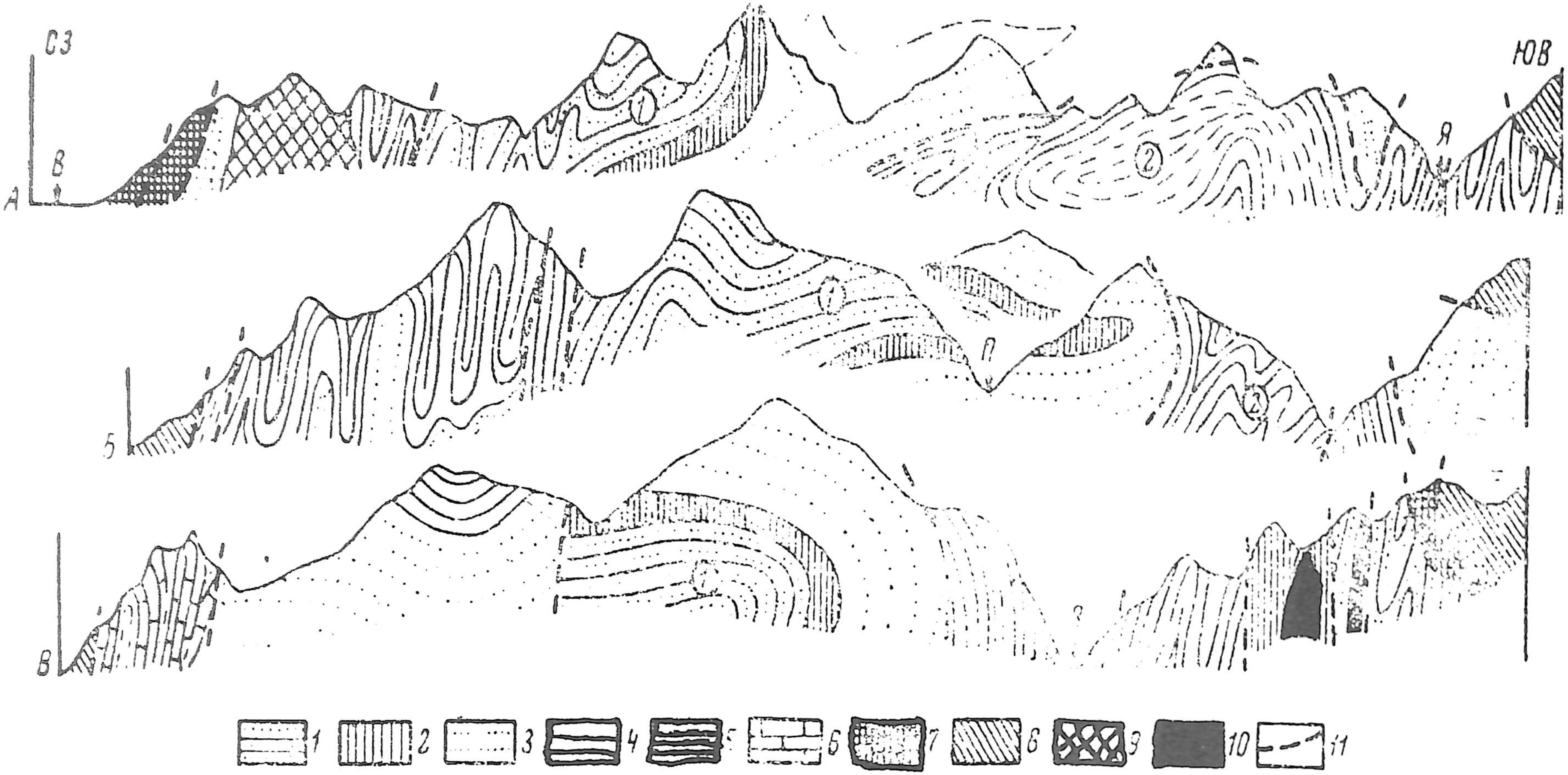


Fig. 7 –. Geological profile through the Vanch antiform (Ruzhentsev, 1971).
1.6 – Autochthonous rocks : 1 – gneisses, schists, quartzites (V-C), 3 – marbles (V-C), 3 – quartzites (V-C), 4 – limestones, ($C-0_1$), 5 – sandstones, claystones (O_{2-3}), 6 – limestones (S_1), 7-8 – allochthon : 7 – limestones, (D_3), 8 – sandstones, claystones (T_3-J_2), 9 – gabbro-diorites (P), 10 – granites (P), 11 – faults. Figures on the profile : 1 – Vanch anticline. 2 – Gudzhivas syncline.

The structure of the allochthon is distinctly different in the west and the east.

In the west the allochthonous rocks constitute the vast Yazgulem synform. It is 90 km long and 30 km wide. Palaeozoic rocks of the Vanch nappe occur as tectonic lenses marking the surface of the main nappe. Their thickness rarely exceeds several hundreds of meters. The Yazgulem nappe is very thick. Its rocks were deformed into various types of folds:

(a) Folds of longitudinal flexure are linear, open, overturned or inclined to the south, with amplitude ranging upto 3.5 km. Gentle bending of apex layers is typical. Usually they owe their origin due to symmetrical deformation confined below a shear surface. There structures may be regarded to have resulted from horizontally oriented compressions which were manifested only in Mesozoic time.

(b) The longitudinal flexure folds of the second type are elongated, recumbent (overturned) or isoclinal with an amplitude of 15 km. The larger is the amplitude, the lesser is stratigraphical range of deposits constituting the fold. Asymmetric folds are also observed. The recumbent folds are of later origin. In places, the shapes of folds are of refolded type (Fig. 8).

The associated folds are also disharmonic and were formed mainly during folding of Upper Jurassic and Cretaceous deposits under the influence of surface tangential forces. Folds with sheared and broken limbs are also distinguished. In the initial stage, the thrusting went on by gliding of the fold-body which in sequel was followed by rolling of the apex.

The structures of the allochthon in the east are different. The three detached nappes which resulted from the sheeting of the allochthon are the Akbaital, Tuzbel and Chabatang. All of them are deformed and range in thickness from 2 to 3 km. Frequently, the plates within their boundaries are folded into comb-shaped anticlines separated by wide, flat synclines. Shears have developed along the overturned limbs of anticlines. It can be observed that a suspended limb of anticline got gradually transformed into an overthrust plate and hence some of the sheets are very thin (Fig. 9) and are typically seen in nappes of the eastern part of the Central Pamir.

The system of folds developed in rocks of the eastern part of the region is of similar steep type (e.g. Yazgulem nappe). Field observations between different types of folds and dislocations within allochthon indicate that formation, shearing and displacement of the allochthon took place in a single episode.

As mentioned above, within the autochthonous rocks two distinct zones: northern (Vanch-Akbaital) and southern (Muzkol) can be noticed. The first one consists of Pre-Cambrian, Lower and Middle Palaeozoic deposits; the second one is constituted by Pre-Cambrian, Upper Palaeozoic, Mesozoic and Cenozoic deposits. The allochthonous sequence includes Lower and Middle Palaeozoic rocks, similar to those distributed within the Vanch autochthon, as well as Upper Palaeozoic, Mesozoic and Cenozoic deposits, which differ from synchronous deposits of the Muzkol zone. On this basis, it was concluded that the allochthonous rocks initially occupied the northern zone and then were dislocated towards the southern zone. In other words, the Vanch~Akbaital zone is a "root region" of the nappes of Central Pamir.

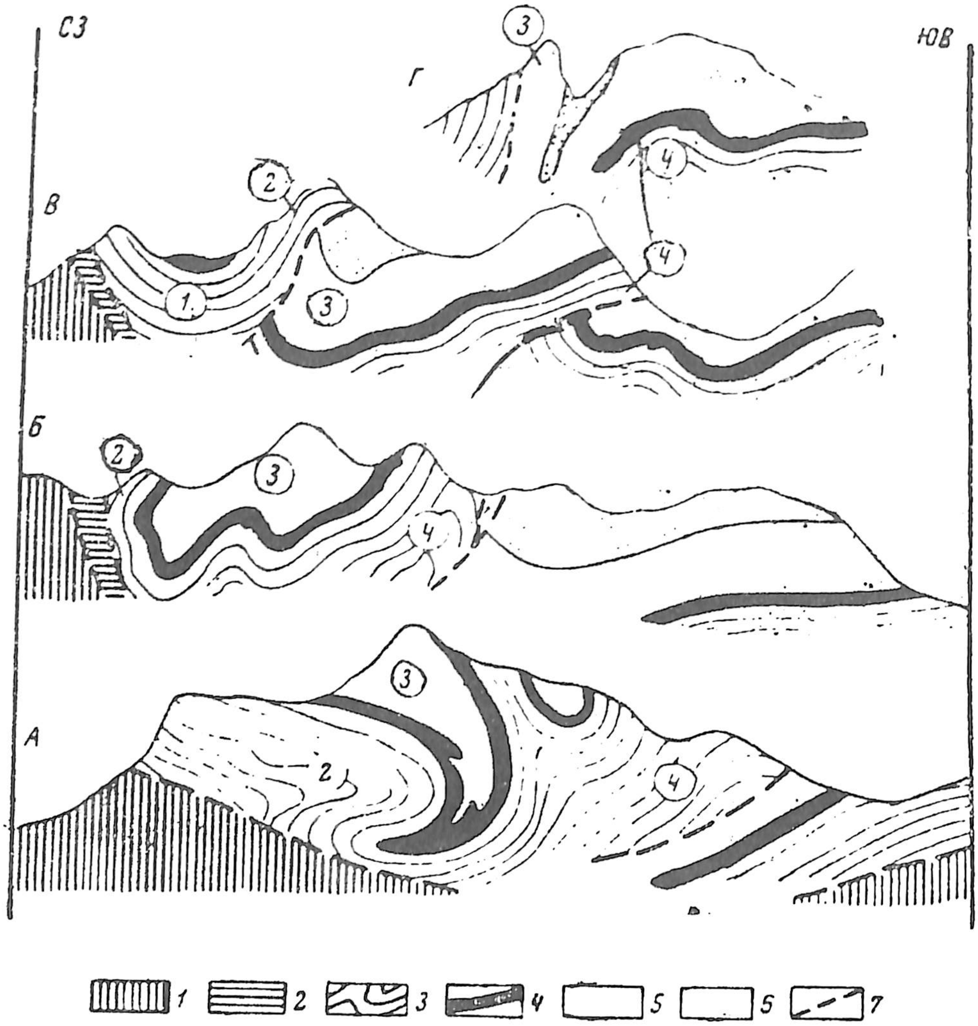


Fig. 8. Geological profile of the Yazgulem ridge,
1 - schists, quartzites, marbles, (V-C), 2 - limestones (D_3), 3 - sandstones (T_3-J_2), 4 - marls (J_2-$_3$), 5 - limestones (J_3), 5 - sandstones (J_3-K_4), 7 - faults.

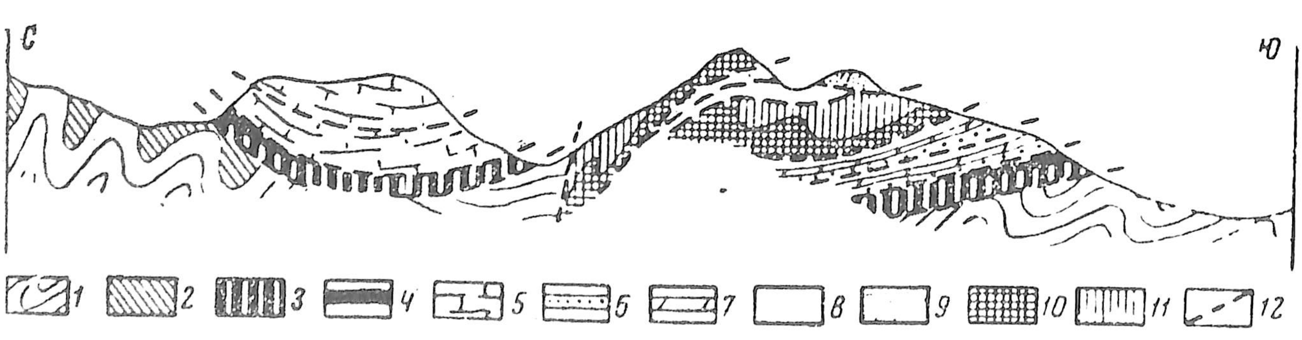


Fig. 9. Geological profile of the Chabarang massif.
1-4 - Parautochthonous rocks: 1 - sandstones (T_3-J_2), 2 - marls (J_2-J_3), 3 - limestones (K_2), 4 - andesites (P); 5-II - allochthonous rocks: 5 - Vanch nappe-Limestones (D-P), 6-g - Tuzbel nappe: 6 - sandstones (T_3-J_2), 7 - marls (J_{2-3}), 8 - limestones (J_3). 9-11 - Chabarang nappe: 9 - sandstones (J_3-K_1), 10 - limestones (K_2), 11 - conglomerates (p), 19 - faults.

The displacement occurred during the Oligocene-time. The visible amplitude of the displacement is recorded for at least 60 km. This was perhaps, much more.

The process of tectonic sheeting of the crust served the basis of nappe formation. The shears were associated with relatively thin plastic horizon (Permian/Triassic marls and limestones) or to border-surfaces of the lithologies (contact between Pre-Cambrian quartzites, and Cambrian-Ordovician limestones) or to the surface of regional unconformity (boundary between Triassic/Jurassic and Upper Cretaceous deposits). Shearing movements also controlled the appearance of a system of structural horizons. Intensity of horizontal compression in each case was different. Study of tension and amplitude of folds indicates that maximum compression occurred in the autochthon (especially much more in its Pre-Cambrian part). The compression within overlying cover was not much considerable, i.e. detachment of the cover was determined by more intensive, layer-by-layer displacement of basement masses. The tensions confined at the base and roof of the parautochthon caused the formation of small folds and complex thrusts. Thus, overthrusting resulted in sheeting of the crust into a system of detached sheets.

Additional compression which took place later, witnessed concentration of deformations on the "Alpine lines" (root zones) as a result of which the width of the autochthon was reduced to a great extent. During the period overthrusting of the Vanch (Akbaital) and Yazgulem nappes occurred. The sedimentary cover was detached from its basement (northern part of the Central Pamir) and moved southward over tens of kilometers. Linear steep folds together with a system of sheets were formed within the allochthon.

Recumbent and overturned folds in the western part of the Central Pamir appeared due to an additional gravitational effect. Essentially, they were formed in such places where a large uplift existed (e.g. rare parts of Vanch antiform). Its elevation created a structural slope, which provided an additional southward sliding of the nappe masses.

South Pamir: Its nappe structure is similar to that of the Central Pamir. The detached nappes, in many ways, determined the structural style of the region. As mentioned above, nappes and large overthrusts were formed not only within the sedimentary cover (South-East Pamir) but also within the basement (South-West Pamir). There are sufficient grounds to believe that Pre-Cambrian basement witnessed compression for a long time. Overthrusts and associated recumbent flow folds are frequently observed in the region. The amplitude of these structures is much greater than that of the Central Pamir. Saklani (1998) also reported serformation of nappes in the Lesser Himalaya (Garhwal) which are characterised by recumbent fold and overthrusts.

The Alpine structure of the South-East Pamir includes two large north-west trending overthrusts. Their strike repeats the pattern of facies zones of Permian-Triassic and Jurassic (Fig. 1). The Gurumda overthrust is internal and the Murgab overthrust is external. The displacement surfaces are characterized by superposition of Permian-Triassic deposits over Jurassic deposits. Overthrust surfaces occur inside the trough of South-East Pamir. Three large units: internal, middle and external (Fig. 6) can be distinguished by their special structural feature. Possibly, the tension decreased towards the internal parts of the South-East Pamir.

In the east, the Gurumda overthrust brought the Carboniferous, Permian and Triassic rocks to pile over the Jurassic rocks. Its amplitude is recorded for about 5-7 km. Correspondingly, the rocks within the recumbent limb are less deformed. Convergence of Permian-Triassic and Jurassic facies is insignificant. In the west, the situation is quite different. Displacement surfaces exhibit a layered disposition. Jurassic rocks were deformed much different from the rocks of Permian/Triassic age. Simultaneously, the overthrust amplitude increased. Even the visible amplitude here is about 15-20 km. Calculations of facies convergence indicate that amplitude of overthrust ranged upto 50 km in length. Morphology of Permian-Triassic structures also changed considerably. As such, in place of simple brachyform structures compressed isoclinal folds were formed.

The Murgab overthrust has an amplitude of 17-20 km.

Horizontal compression, manifested in itself unevenly over the South-East Pamir territory. It resulted in sheeting of the crust into separate, heterogenously deformed structural horizons. In the Central Pamir the maximum compression existed at deep-seated levels.

Fanning of the northern and southwestern systems of overthrust planes dipping towards the central part of the trough, can be ascribed to movements of the marginal parts of the South-East Pamir.

North Pamir: Nappe structures are developed in the Kalaikhumb zone whereby the Lower-Middle Palaeozoic rocks, previously formed in the southern part (Kurgovat zone), were overthrust northwards and structurally coincided with the Lower Carboniferous ophiolites.

The nappe relations have been studied in the South-West Darvaz (Ruzhentsev et al., 1977). Structurally, the region is characterized by simple antiforms and synforms (Fig. 10), Carboniferous volcanogenic deposits occur in the core of the antiforms. Devonian sandstones and limestones constitute the core of the synforms. The simplest structures have been observed in the northern part of the region, where Lower and Middle Palaeozoic rocks occur in horizontal outliers.

Southwards, the allochthon is dislocated in a more complicated manner. The single plate is split into separate sheets as a result of which the succession of layers is frequently disturbed. For example, Carboniferous rocks (limestones) are overlain by Silurian-Devonian limestones, overlapped by Ordovician sandstones.

In the field it is observed that Silurian-Devonian limestones, overlying the Carboniferous olistostrome are. tilted and formed the front of the overturned fold with Carboniferous rocks which overlie the Silurian-Devonian rocks underlain by Ordovician sandstones (Fig. 10).

The structure of the Kalaikhumb zone is determined by a large, overturned synform. Its flat limb is exposed in the northern part of the region while the suspended limb and the apex are exposed in the southern part.

The synform in turn is thrust on the Proterozoic gneisses and crystalline schists (base of the Kurgovat zone). The overthrust plane is marked by a belt of serpentinite-melange.

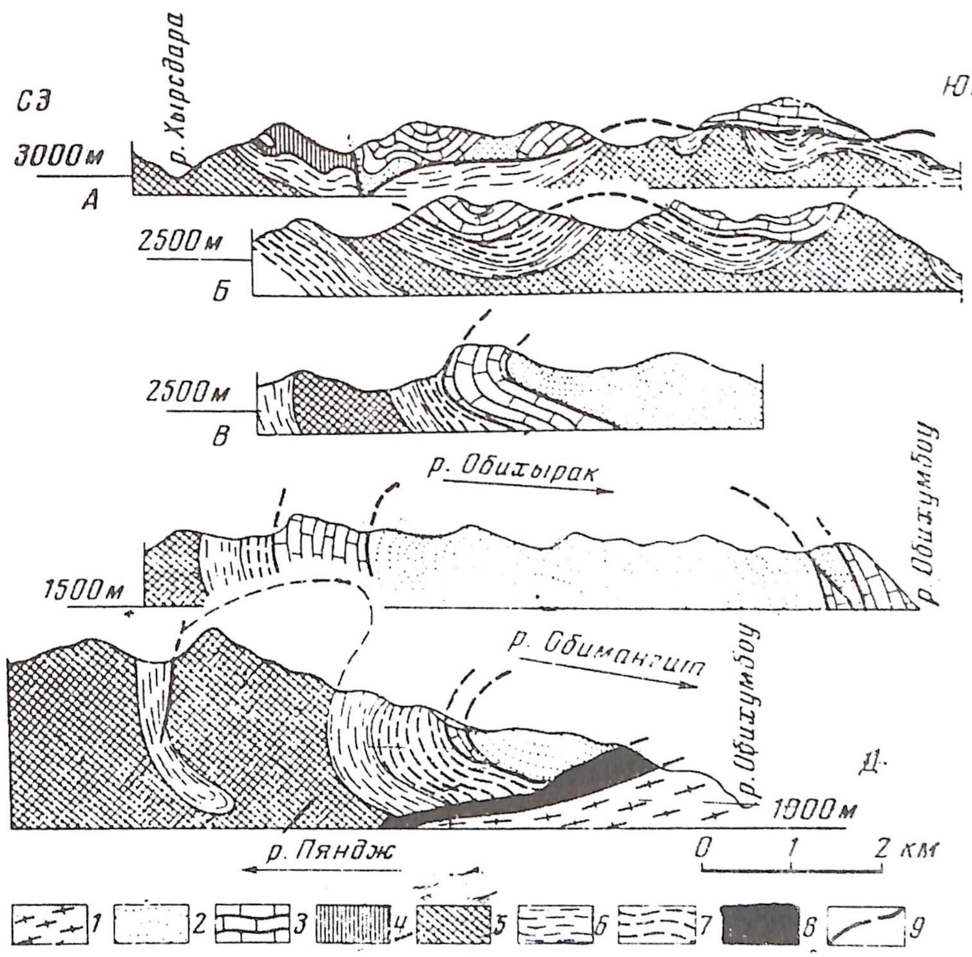


Fig. 10. Geological profiles of the South-West Darvaz.
I - sneisses, schists (PR1), 2 - sandstones, phyllites (V-O), 3 - limestones (S-D), 4- limestones (C1t-n), 5 - basalts (C1t ?-n), 6 - andesites, liparites and toffs (C1n1-2), 7 - olistostrome, claystones (C1n2-C2 ?), 8 - serpentinites, 9 - faults.

Further, the sedimentary cover (Devonian) was thrust over the ophiolites. The formation of detached North Parnir nappes was determined by the structural splitting of the continental crust.

Allochthonous sheets were thrust northward and their root was situated in the northern part within the Kurgovat zone which is constituted by Lower, Middle Palaeozoic rocks. The overthrusting of a single thick sequence of rocks was characterized by its splitting into several separate sheets.

The amplitude of overthrusting ranged upto 30 km along the width of the Kalaikhumb zone. It was folded (together with autochthon)into a vast overturned southward synform consisting of allochthonous rocks.

The overthrusting of rocks took place in the Middle Carboniferous times. In contrast to this, thrusting of rocks is Tertiary in the Himalayan orogen (Saklani, 1998).

SCOPE OR STUDIES

This work briefly deals with the nappes. Their study has been possible through field observations. The youngest (Late Alpine) deep-seated overthrusts and associated large transcurrent faults have not been discussed here because of the limited consideration of the morphology, initial level of formation, amplitude and plainspastics.

The Pamir region consists of detachments and faults (Peive, 1967; Pieve et al. 1964; Knipper and Ruzhentsev, 1977). The former are surfaces which separate the differentially displaced layers of lithosphere and these may determine independently whether the asthenosphere or the cover and crystalline basement boundary were involved. The detachments concerned are always (from the movement of layer formation) zones with higher tectonic activity. Such detachments are particularly numerous in the cover. Here they are less persistent along the trend and displacement amplitudes along them are smaller. However, in principle, their mode of formation is probably the same.

Morphologically, the surrounding faults are strike-slips, overthrusts, anti gaping faults. We have mainly dealt with overthrusts, particularly those, which in process of development are transformed into nappes. Genetic problems of overthrusting would need additional studies. Here, it should be mentioned that depending on overthrusting mechanism and structure of displaced series, various structural futures of nappes were formed. In the Pamir, nappe plates predominate in the eastern part of the Central, South, South-West and South-East Pamir. Nappe folds with amplitude upto 30 km and more are widely distributed here. Folds with Iongitudinal bend, and deepseated surface folds (western part of the Central Pamir) are most frequent. Morphologically, they are diversified, ranging between vast, relatively simple deep-seated folds which on the surface show numerous digitations. Besides, there are nappe flow folds, similar to the well known nappes of the Pennines.

The third type of dislocations are observed in the North Pamir and they are represented by allochthonous plates deformed into folded nappes. Their formation is connected with a process of retro-overthrusting.

REFERENCES

Belov, A.A., Knipper, A.L. and Ruzhentsev, S.V., 1976: Histrorico-tectonical and structural interpretation of granite-gneissic massifs of the Alpine folded area In: "*Tektonika Srednikh massivov*". M., "Nauka". (in Russian).

Budanova, K.T., 1973: Darshaisk ultrabasitic complex (South-West Pamir). *Izv. Tadjik SSR*, 1(51) (in Russian).

Cherner, E.S. and Budanov, V.I., 1974: New ideas on tectonics of the Pamir. *Doklady AN SSSR*, 214(5) (in Russian).

Dronov, V.L and Andreeva, T.A., 1962: Stratigraphy of Jurassic deposits of Central and South-East Pamirs. Reports of the Soviet geologists at the 1st International meeting on Jurassic system, *Tbilisi. Izdat. An Gruzinsk.* SSR. (in Russian).

Dronov, V.I., Leven, E.Ya., 1961: On geology of the South-East Pamir. "*Sovetskaya geologiya*," 11, (in Russian).

Karapetov, S.S., 1963: Middle Palaeozoic stratigraphy of the Central Pamir. In: "*Materialy po geologii Pamira*", 2, Dushanbe (in Russian).

Knipper, A.S. and Ruzhentsev, S.V., 1977: Deep-seated faults and geosynclinal process. In: "*Razlorny zemnoia kory*", M., "Nauka" (in Russian).

Kushlin, B.K., 1963: Stratigraphy of Triassic deposits of the Central Pamir. In: "*Materialypo geologii Pamira*", 1 (in Russian).

Pashkov, B.R., 1962: On Late Palaeozoic deposits of the Central Pamir. *Geologiya Razvedka*, 7 (in Russian).

Pashkov, B.R. and Shvolman, V.A., 1979: Riftogenie margins of the Tethys in the Pamir. "Geotektonika", (6) (in Russian).

Peive, A.V., 1967: Faults and tectonic movements. "*Geotektonika*", N. 5, (in Russian).

Peive, A.V., Burtman, V.S., Ruzhentsev, S.V. and Suvorov, A.I., 1964: Tectonics of the Pamir-Himalayan sector of Asia. *Doklady sov. geology, XXII sessiya MGK* (in Russian).

Ruzhentsev, S.V., 1968: Tectonic development of the East Pamir and the role of horizontal movements in formation of its Alpine structure. "*Nauka*" (in Russian).

Ruzhentsev, S.V., 1971: Structural peculiarities and mechanism of formation of detached nappes. M., Izdat. "*Nauka*" (in Russian).

Ruzhentsev, S.V., Pospelov, I. and Sukhov, A.M., 1977 : Tectonics o1' the Kalaikhumb-Sauksai zone the North Pamir. "*Geotektonika*". (4) (in Russian).

Saklani, P.S., 1998 : Geology of the Garhwal Himalaya : Retrospect and Prospect, Presidential address of the Earth System Sciences, 85th Session, *Ind., Sci., Cong. Assoc.* 32 p.