Zhidkoye zoloto? Environmental aspects of Natural Gas transportation from the Sakha Republic

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Pembroke College

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Declaration

In accordance with University of Cambridge regulations, I do hereby declare that:

This thesis represents my own original work and conforms to the accepted standards of citation in those instances in which I have availed myself of the works of others.

This thesis is not now being submitted nor has ever been submitted in the past for any other degree, diploma, or any other qualification at any university or similar institution.

This thesis does not exceed the maximum allowable length of 20,000 words excluding: footnotes, tables, appendices and references.

Cambridge, June 1994 Ben Seligman

Front cover photograph: An example of the environmental damage associated with gas pipelines in West Siberia (Tyumen' Oblast'). Photo: Peter Williams.

Acknowledgements

I have many people to thank for their generous assistance during the months leading up to the completion of this thesis. Before acknowledging them, I must thank my college, Pembroke, and the Scott Polar Research Institute for their generous financial contributions towards my recent trip to Moscow.

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I would also like to thank Stephen Thompson of Intera Information Technologies. The generous information he provided on the emerging oil and gas industries of the Sakha Republic proved invaluable for a substantial part of my research.

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Glossary of Russian Terms and Abbreviations

Note : terms or abbreviations that do not appear here are defined in the text.

A.O. - Autonomous Okrug (district). Administrative subdivision based on nationality groups.

A.S.S.R. - Autonomous Soviet Socialist Republic. Administratively serves the same function as an oblast', but its boundaries have been drawn up to give political recognition to an important nationality, often a minority.

A.Y.A.M. - Amur-Yakutsk Mainline railway. When completed, will link Bamovskaya (on the Trans-Siberian Railway) and Tynda (on the B.A.M.) with Yakutsk. Total length laid to date : ca.500 km (as far as Aldan). Total length when completed : ca.1230 km.

B.A.M. - Baikal-Amur Mainline railway. Runs north of the Trans-Siberian Railway between Tayshet (Irkutsk Oblast') and Vanino (Khabarovsk Kray) on the Pacific coast. Total length : 3115 km.

Glavsevmorput' - Main Administration for the Northern Sea Route.

Goltsy ice - (normally referred to as '*goltsy*' but correctly transliterated as '*gol'tsy*'). Goltsy is a Siberian name for elevations which extend beyond the timber line. Therefore, goltsy ice is that which lies beyond this line.

Kray - Region. A combination of Oblast' and A.S.S.R. Its boundaries have been laid out primarily for administrative purposes, but it contains within it lesser political subdivisions that are based on nationality groups, for example *A.O.*s.

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Mari - Sparse larch forest with peat moss litter; shallow, often humocky, bog.

Oblast' - Region. A purely administrative subdivision that contains no significant nationality group other than the titular nationality of the Russian Federation.

Rayon (pl. *rayony*)- *Oblasts*, *Krays* and *A.S.S.R.*s are divided into *rayons* which are small districts, similar in function to counties.

Solonchak - an intrazonal soil in which soluble salts are present in considerable quantity. Of widespread occurrence wherever there is a sufficient degree of evaporation, both in hot deserts and in cooler continental interiors where summer heat allows seasonal evaporation.

Solonets - A saline soil in an area with appreciable rainfall, so that some salt in the surface layer is leached out, to be concentrated in a lower horizon.

Sovkhoz (pl. *sovkhozy*) - State farm.

Suglinok - derived from the word '*glina*' (clay). *Suglinok* is a silt which contains sand and clay, though predominantly clay. Clay content (%) by weight : 30-10.

Supes - derived from the word '*pesok*' (sand). *Supes* is a silt which contains sand and clay, though predominantly sand. Clay content (%) by weight : 10-3.

Glossary of Technical Abbreviations

BCM - Billion cubic metres.

CDP - Common Depth Point (applies to multi-channel reflection seismic surveying).

dwt - Dead weight tonnage.

in - inches.

LNG - Liquefied Natural Gas.

MCM - Million cubic metres.

MPa - Mega pascals. 1 MPa = 142 psi.

psi - pounds per square inch.

TCM - Trillion cubic metres.

Note on Transliteration

This thesis employs the system of transliteration used in the journal *Post Soviet Geography*. This is also the standard system for the Scott Polar Research Institute.

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Abstract

The Sakha Republic, Russia's largest administrative unit, could in ten years time be well on its way to becoming a major source of natural gas for a number of Pacific Rim nations, where demand for LNG (Liquefied Natural Gas) is growing rapidly. Already, Japanese and South Korean consortia are engaged in pre-feasibility studies for a trans-continental gas pipeline linking the Sakha gas fields with the Korean peninsula and Honshu. This pipeline will be faced not only with political obstacles, such as those evident within Russia and on the Korean peninsula, but also a wide variety of constraints imposed by regional environmental peculiarities. These would create special problems for a long-distance gas pipeline. The environmental implications are far reaching. The West Siberian oil and gas region has suffered severe environmental damage caused by the undesirable interactions between pipelines and the surrounding environment. Pipeline construction activities have also contributed to the overall situation. In view of the climatic variability, variations in permafrost continuity and numerous mountain ranges in particular that characterize the Russian Far East, this thesis argues that a gas pipeline from the Sakha Republic should be laid eastwards rather than southwards, direct to markets. A pipeline transmitting gas to a liquefaction plant on the Sea of Okhotsk coast for onwards shipment by LNG tankers, would face fewer environmental constraints, would be relatively economical and would be favourable from the point of view of the republic's human geography. The reasons behind this contention are examined in detail. Also considered are current developments in environmental legislation for foreign investors in Russia's oil and gas sectors.

Chapter 1

Introduction

1.1 BACKGROUND.

1.1.1 Explanation of the title.

Natural gas in its liquefied form (LNG) has been referred to in some Russian texts as *Zhidkoye zoloto* (liquid gold). The growth in demand for LNG, particularly in the Pacific Rim (see Pezeshki & Fesharaki, 1994, p.6), is a major part of the global realization of the value of this energy resource. Gas is a clean burning fuel, unlike oil and coal, and so from an environmental point of view it is highly desirable. However, it is important to note that this environmental 'plus point' only applies to the use of the commodity once within its markets. The assumption fails to take into account anything that happens *before* this energy resource reaches its markets. A judgement upon a resource's environmental expediency can only be made after one has added the pre-usage stage to the equation. This pre-usage stage includes the extraction and transportation (to market) of the resource. Only after this stage has been acknowledged are we in a position to pose the question: is natural gas 'environmentally sound'? In essence, I am asking the question: is natural gas as environmentally expedient as it is made out to be? Hence the question mark in the title.

The title also indicates that I will be examining the transport aspect of this question alone. The transportation of the product itself raises plenty of questions surrounding for example the risks taken when pumping gas through long distance, large diameter, high pressure pipelines. Risks are inevitably higher when this question is applied to a 'pioneering resource region' (little developed) which lies many hundreds or thousands of kilometres from markets. Such pioneering regions are fewer today than ever before. The depletion of energy resources in more accessible regions, the growth in demand for natural gas in particular, and the development of new extraction and transportation technologies has meant that new resource frontiers are being sought in earnest. The former Soviet Union holds within its vast Arctic and Subarctic expanses a high percentage of the

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1.1.2 An introduction to the Sakha Republic.

The republic is located in the Russian Far East economic region, as shown in Fig.1.1, and its capital,Yakutsk, lies approximately 5000 km northeast of Moscow (seven hours by plane). Sakha is the largest administrative division within the Russian Federation. It has an area of 3.1 million km², making it larger than the entire West Siberian economic region, and a population of only 1,098,900 (1990 figures from *Goskomstat* RSFSR, 1990, p.45), of which 66.7% is urban and 33.3% is rural. Settlements are small. Yakutsk has a population of less than 200,000, while the republic's six other 'cities' have much smaller populations (Olekminsk for example has a population of 11,500).

The republic's size and extremely harsh climate have hampered development efforts and this is reflected for example in the republic's inadequate transport infrastructure. Tundra and tundra-taiga characterize the vast northern tracts, while mile upon mile of forest[1] covers central and southern Sakha.

Until the republic gained independence in 1992[2], its designation was the Yakut Autonomous Soviet Socialist Republic (ASSR) or Yakutia, which came into being on 27th April 1922. The republic's true indigenous inhabitants are chiefly the Eveny and Evenki, while the Yakuts, a far more numerous people, moved into the region during the middle ages and over time pushed the smaller peoples northwards. The first Russians arrived in the 17th century, seeking furs and other riches. Nowadays, the republic has a predominantly immigrant population. Since independence the Yakut government has discouraged immigration and with decreasing salaries and worsening living conditions, many Ukrainian, Belorussian and Russian immigrants are eager to leave.

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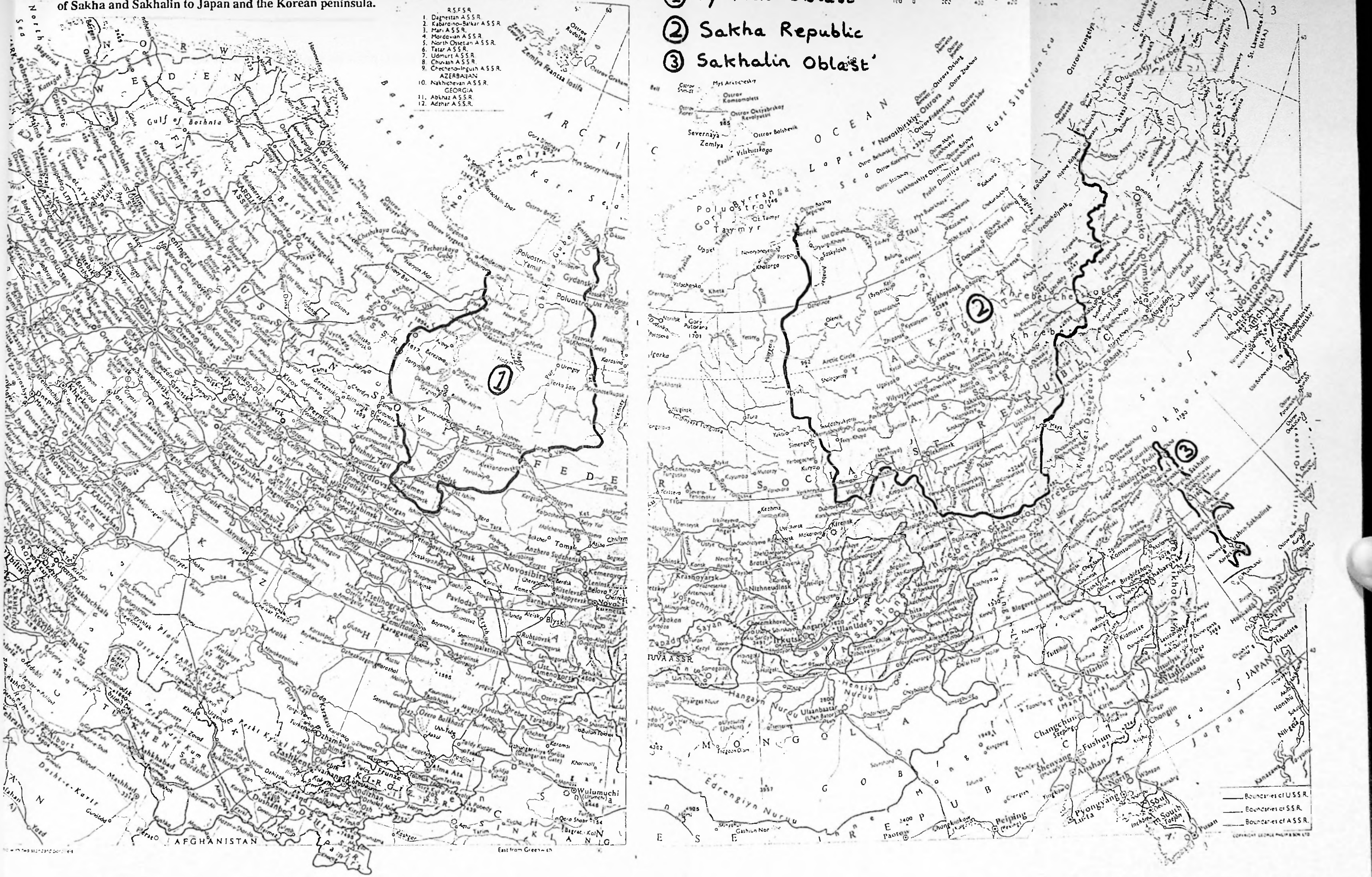
[1]Part of the taiga zone that stretches for 10,000 km across Russia between the Baltic in the west and the Sea of Okhotsk in the east
[2]Sakha is the Yakut self-appellation.

Figure 1.1 Map showing the Sakha Republic in relation to other administrative divisions of the Russian Federation, including Tyumen' Oblast' and Sakhalin Oblast'. Note also the proximity of Sakha and Sakhalin to Japan and the Korean peninsula.



The Sakha Republic is laden with natural riches, the most significant of these being coal (exported to Japan and South Korea), iron ore, gold, tin, phosphates and diamonds[3]. In comparison with estimates of Sakha's potential gas reserves, its current gas production statistics seem pathetic. The Far East's proven natural gas reserves are located predominantly within the republic; Sakhalin Island is the only other noteworthy natural gas storehouse within the region. At present, it is impossible to say exactly how much natural gas might be hidden within the bowels of the republic, but some estimates have put the figure for potential reserves as high as 107 TCM (Leaver, 1992, p.63). Current estimates for recoverable reserves are approximately 1.3 TCM (Intera & *Sakhaneftegaz*, 1993)[4]. Studies carried out so far have shown that Sakha's natural gas potential is vast. For this reason President Mikhail Nikolayev is keen to attract foreign investment in both the oil and gas sectors (Nikolayev, 1992, p.11) and the republic has attracted much attention from an increasing number of emerging natural gas (particularly LNG) markets. Most significant are those located within the Pacific Rim, for example Japan, South Korea and Taiwan. Indonesia has been a major source of LNG, but reserves there are being depleted rapidly and the Pacific Rim consumers are looking for new suppliers, some of which are located in the Middle East (e.g. Qatar, Oman and the United Arab Emirates). The Russian Far East lies much closer to these emerging markets than potential long-term Middle Eastern suppliers. For this reason, two Japanese companies, Mitsui and Mitsubishi, are members of a consortium which will soon start oil and gas production off the coast of Sakhalin Island[5]. The Japanese and South Koreans could be doing the same in the Sakha Republic very early next century.

1.2 THESIS STRUCTURE.

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[3]In 1990, 98% of Russia's diamonds came from western Sakha (Manezhev, 1993, p.18).

[4]Until detailed studies have been carried out by western geophysicists, all gas reserve estimates for the Sakha Republic should be treated with caution. Virtually every author mentions different figures and for this reason it would be unacceptable to quote one of these figures on its own. At the very least, a wide range of figures should be used when citing estimates.

[5]Sakhalin and Hokkaido are separated by the 50 km wide La Pérouse Straits.

The Sakha Republic is laden with mineral riches, the most significant of these being coal (needed by Japan and South Korea), iron ore, gold, tin, phosphates and diamonds[illegible]. In comparison, the [illegible] of Sakha's potential gas reserves, its current gas production [illegible]. Despite Sakha's proven natural gas reserves [illegible] within the republic, Sakhalin is the only other [illegible]. At present, it is [illegible] [illegible] (Sakha) [illegible] [illegible] [illegible] [illegible] the Middle East [illegible] [illegible] [illegible] [illegible] [illegible] The Japanese and South Koreans would be [illegible] the Sakha Republic [illegible].

[illegible] STRUCTURES.

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[illegible]

The Japanese and South Koreans have planned to undertake feasibility studies for a gas pipeline linking central Sakha with the Korean peninsula and Honshu. This pipeline, north - south oriented, is likely to come up against numerous obstacles, both physical (distance, permafrost, mountains, earthquake-prone zones), economic (Arctic / Subarctic pipelines costs approximately $50,000 per inch [diameter] per km) and political (the pipeline would have to pass through North Korea). From an environmental standpoint (although economic and political factors are considered briefly), I argue that it would be more expedient to construct a shorter pipeline oriented west - east, running from the gas fields of central Sakha to the Sea of Okhotsk coast. From there the gas, having been liquefied, would be taken by tanker to markets[6]. In this case, the pipeline would lie almost entirely within the Sakha Republic, though the easternmost section would pass through northern Khabarovsk Kray and possibly southwestern Magadan Oblast'.

With impending large-scale hydrocarbon exploitation and supply systems construction in pioneering regions of the Russian Federation, it is essential that long-term research programmes investigating local environmental characteristics and environment-pipeline interactions are prioritized. Such work can be optimized through cooperative projects between Russian specialists and their western counterparts. These pioneering regions tend to be in Russia's Arctic and Subarctic zones and therefore it is particularly important that research focuses on permafrost and the unique problems it poses for pipeline construction and operation. This thesis examines many of these problems and represents, as far as the author knows, a unique applied study which suggests possible solutions to some of these problems in the context of a particular region soon to be opened up to large-scale natural gas exploitation and pipeline construction.

The oil and gas industries of the former Soviet Union always have been and will remain crucial for the economy to continue to industrialize and, with the help of exports, to purchase equipment and technology from abroad (Stern, 1993, p.4). The industries of course provide fuel to consumers throughout this vast land mass via an immense network of pipelines. Behind this

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[6]Owing to the brevity of this thesis, the tanker sector of this supply route is not considered within the main text. Appendix 2 does however present some of the more important points regarding this sector.

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[illegible]

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monument of Soviet socialism lies a terrible legacy. Russia, and in particular its Arctic and Subarctic region where the largest fuel reserves are located, has paid a heavy penalty for the rapid development of oil and gas fields and supply systems. The environment has been quite literally pillaged and the scale of the environmental damage is colossal.

The region that has suffered most is Tyumen' Oblast' (West Siberia[7]), which is the source of the vast majority of Russia's oil and gas. Much of the damage has been caused by the construction and operation of supply systems, namely oil and gas pipelines. The current environmental situation in Tyumen' Oblast' is a tragic example of what happens when an intense desire for rapid production and expansion is put ahead of concerns for the environment. In this case, the environment has played virtually no part at all in the decision making processes surrounding oil and gas development. The Tyumen' catastrophe therefore has been used in chapter 2 to demonstrate how the development of long-distance pipelines can have serious environmental repercussions if necessary measures relating to planning, configuration, temperature regime and construction are ignored. Above all, decisions regarding northern pipeline construction and operation have to include special consideration of possible interactions between the pipeline and the surrounding permafrost.

Pipeline projects in northern Russia involve truly massive investments[8]. This can be attributed to the length of the pipelines, their remoteness from markets, the special equipment and technology necessary for development under such harsh climatic conditions and the fact that projects generally involve additional exploration and production stages. This is one reason why consortia comprising local, national and foreign companies are central to any large development project in Russia. When projects run into the billions of dollars category, the involvement of well-established western companies is imperative. However, the turmoil surrounding the collapse of communism and Russia's struggle to revive its ailing economy have left the country in tatters. It would be an

[7]Of the 392 million tons of oil produced in 1992 in the Russian Federation, approximately 245 million tons came from West Siberia. Of the 640 BCM of gas produced in 1992 in Russia, approximately 560 BCM came from West Siberia (*Russian Petroleum Investor*, 1994a, p.10).

[8]The total development cost of the recently proposed Timan-Pechora Project (which would lead to production from up to 11 oil fields), involving a consortium consisting of Texaco, Norsk Hydro, Amoco and Exxon, could require investments of some $58 billion over the next 50 years. This is a true 'megaproject'.

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[4] Of the 302 million tons of oil produced in 1993 in the Russian Federation, approximately 212 million tons came from West Siberia. Of the 600 bcm of gas produced in 1993 in Russia, approximately 550 bcm came from West Siberia (Gazeta, Promyshlennost' Rossii, 1994a, p.101).

[5] The total development cost of the currently proposed Timan-Pechora Project (which [illegible] 14 oil fields), involving a considerable consortium of [illegible], would require investments of some $50 billion over the next 50 years. This is [illegible].

understatement to suggest that contemporary Russia is not a safe operating environment for western companies. Given the huge reserves, they are eager to participate in the revitalization of the Russian oil and gas industries, but the absence of a sound taxation system, insurance and export policies, as well as foreign investment and environmental legislation has put many potential foreign investors off. The Russians realize they can do little without western investment and so they have recently begun to transform this inhospitable and unstable foreign investment environment into one conducive to successful cooperative projects. Their efforts to develop environmental legislation for foreign investors in oil and gas projects are outlined in the second half of chapter 2.

The Sakha Republic's immature natural gas industry is examined in chapter 3. While its short history and current status are considered, special attention is given to the republic's poorly developed pipeline system. Its first gas pipeline, viewed as experimental at the time of construction, was the first ever to be built in permafrost. The second half of the chapter outlines past and present foreign interest and involvement in the development of Sakha's gas. Noteworthy are the Japanese and Korean desires to produce and export gas via 5000 km pipelines. Critical to any pipeline project in Sakha is the state of resource ownership rights and foreign investment laws. As shall be seen, these are both highly unpredictable and likely to cause considerable problems during the planning phase of any project.

Together chapters 4 and 5 provide an overview of the two-stage process necessary for ensuring that a long-distance large-diameter gas pipeline causes minimal environmental disturbance. Although I have focused upon one particular area of the Russian North, many of the points raised can be easily applied elsewhere both within the Russian North and the Circumpolar North. The first stage, represented in chapter 4, involves an examination of the environmental characteristics of the region through which the pipeline might pass. This is sub-divided into two parts; human geographical characteristics (for example, rural agricultural activities and existing transport infrastructure) and physical geographical characteristics (for example, climate and permafrost). By combining this information with that derived from past and current research into gas pipeline construction and operation in permafrost conditions, one can progress to the second stage. This

involves making decisions regarding for example the pipeline's right-of-way (route), configuration (above, on or ground), thermal regime (warm or chilled) and construction. Given the small scale of this thesis, the intention is to offer suggestions alone, though these represent useful guidelines.

Some concluding remarks are offered in chapter 6. The conclusion aims to achieve two main goals. The first is to outline the most important points raised throughout the thesis and the second is to present an answer to the question hinted at in the title and described in section 1.1.1. The second stage of the natural gas export route, the tanker section, will be considered briefly.

1.3 DESCRIPTION OF RESEARCH METHODS.

The information for this thesis has been derived from a plethora of sources during three separate research phases. The first phase took the form of a field trip to the Sakha Republic from 19th July to 31st August 1993. The aim of this trip was not to focus specifically upon the subject of this thesis, but to carry out a general study of the region. A specialized study would have been unrealistic given the difficulties one faces when trying to arrange visits to specific locations within the republic. Such difficulties stem from an unpredictable transport network (flights, river trips and bus journeys can be cancelled without notice) and the fact that it is now nearly impossible to gain access to the vast interior of the republic, i.e. away from the major rivers such as the Lena, because scheduled internal flights and helicopter charters in particular are staggeringly expensive. Nevertheless, I was able to visit some of Sakha's remotest areas, namely the Lena delta and the coal mining centre and former *gulag* Zyryanka, located in the upper Kolyma. Specific to this thesis, I made two short visits to the *Institut Merzlotovedeniya* (Institute of Permafrost Studies), Yakutsk, and acquired valuable data concerning the republic's permafrost. Extensive journeys on the River Lena, between Olekminsk in the south and Tiksi on the Laptev Sea coast, provided useful data for chapter 4 (human geographical characteristics).

The second phase involved a short trip to Moscow, 13th to 24th April 1994, which was geared specifically towards data collection for this thesis. The main purpose of the trip was to attend involves making decisions regarding, for example, the pipeline's right-of-way (route), configuration (down, on or aground), thermal regime (warm or chilled) and construction. Given the small scale of this thesis, the intention is to offer suggestions alone, though these represent useful guidelines.

Some concluding remarks are offered in chapter 6. The conclusion aims to achieve two main goals. The first is to outline the most important points raised throughout the thesis, and the second is to present an answer to the question raised at in the title and described in section 1.1. The second stage of the natural gas export route, the marine section, will be considered briefly.

1.3 DESCRIPTION OF RESEARCH METHODS

The information for this thesis has been collected during a period of fieldwork during three separate research phases. The first phase took the form of a field trip to Yakutsk, Republic Sakha, from 20th July to 31st August 1993. The aim of this trip was not to focus specifically on the subject of this thesis, but to carry out a general study of the region. A reconnaissance study would have been impossible given the difficulties one faces when trying to arrange visits to specific locations within the republic. Such difficulties stem from an unpredictable transport network (flights, river trips and bus journeys can be cancelled without notice) and the fact that it is now nearly impossible to gain access to the vast interior of the republic, i.e. away from the major rivers such as the Lena, because helicopters, internal flights and helicopter charters in particular are staggeringly expensive. Nevertheless, I was able to visit some of Sakha's remotest areas, namely the Lena delta and the coal mining towns and former gold [illegible] in the upper [illegible]. Specific to this thesis, I made two short visits to the [illegible] (Institute of Permafrost Studies), Yakutsk, and acquired valuable data regarding the republic's [illegible]. Extensive journeys on the River Lena, between [illegible] in the south and Tiksi on the Laptev Sea coast, provided useful data for chapter 4 (natural geographical characteristics).

The second phase involved a short trip to Moscow, 17th to 24th April 1994, which was aimed specifically towards data collection for this thesis. The main purpose of the trip was to attend the Third Moscow International Oil and Gas Projects Conference (20th to 21st April). This was a valuable opportunity to learn more about the current status of Russia's oil and gas industries. Of particular interest were the sessions on environmental legislation in the context of foreign investment and the overall theme of the conference which involved western companies describing how the Russians can benefit from their capital, technologies, productivity, experience and environmental conscientiousness. This conference coincided with the five day Moscow International Oil and Gas Exhibition (MIOGE '94; 18th to 22nd April) which was a valuable source of information on certain aspects of pipeline construction. I was also fortunate enough to conduct an informal interview with Amir Amirkhanov, Deputy Minister of Environmental Protection and Natural Resources. He provided me with information concerning rights to natural resources, the position of native peoples in the context of resource development, and recent developments in environmental law in the oil and gas industry.

The third phase involved research in the U.K. which took two forms. First, visits were made to Smith Rea Energy Analysts, Canterbury, where I was given access to recent reports on the Russian gas industry, and to BP Exploration, Sunbury-on-Thames, where I was provided with information concerning gas pipeline construction and operation in areas of permafrost. I also received information on ice-strengthened LNG tankers, environmental aspects of oil and gas exploration and production in the Arctic and revegetation trials on the Yamal Peninsula. Invaluable information on the Sakha Republic's oil and gas industry was provided by Intera Information Technologies, Henley-on-Thames. The second involved library research. The Scott Polar Research Institute Library, Cambridge University, and the British Library (Scientific Reference Library, London) proved most useful. Efforts have been made to use Russian sources wherever possible and when most appropriate. Where fitting, comparisons between Russian and western sources have been made.

Chapter 2

The West Siberian Environmental Legacy and Changing Russian Environmental Legislation for the Oil and Gas Industries

2.1 GAS PIPELINES IN WEST SIBERIA : AN ENVIRONMENTAL PERSPECTIVE

2.1.1 Setting the scene

Environmental protection in Russia has traditionally been an anathema. Industrial development of the Russian North has been synonymous with a blatant lack of respect for the environment. The "Mastery of the North" (*Osvoyeniye severa*) involved extracting all that was possible in as short a time as possible, for as little as possible, whatever the cost to the surrounding taiga and the indigenous peoples (who represent a key component within the inhospitable northern environment). Nowhere has this been more apparent than in the northern tracts of the West Siberian economic region, the major source area of Russian natural gas[1]. The following comparatively recent quotation from a representative of *Neftegazstroy* and *Mingazprom*[2] clearly illustrates the grim facts:

> *"The Ministry of Oil and Gas Construction is the construction ministry and we must build gas pipes and not be busy with the devil knows what.... It's not our business to preserve nature and to save reindeer."* (Prokhorov, 1989, p.120).

Tyumen' Oblast' (see Fig.2.1) has seen many decades of this industrial onslaught, ever since the first oil fields were opened up in the early 1960s. In 1990, of the 6200 km² of oil and gas fields in the Yamal-Nenets A.O., the total area of destroyed vegetation was 2500 km² and along pipeline routes the figure was 1800 km² (Vilchek & Bykova, 1992, p.105). The pioneers of the West Siberian oil fields and gas fields, quite justifiably in their own eyes, never looked upon their achievements as anything other than heroic, and there is no end to the triumphant references to "new railways cutting through thick forests" or "pipes laid across marshes, through forests and under big rivers". But the

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[1]West Siberian natural gas production reached 565 BCM (billion cubic metres) in 1991 (Sedykh, 1993, p.65). Paton & Ivantsov (1993, p.4) expect an annual increase in West Siberian production of 40-50 BCM per annum.

[2]*Neftegazstroy*, the Ministry of Oil and Gas Construction, is now *Rosneftegazstroy*. *Mingazprom*, the Ministry of Gas Industry, is now *Gazprom*.

Chapter 2

The West Siberian Environmental Legacy and Changing Russian

Environmental Legislation for the Oil and Gas Industries

2.1 GAS PIPELINES IN WEST SIBERIA: AN ENVIRONMENTAL PERSPECTIVE

2.1.1 Setting the scene

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"The Ministry of Oil and Gas Construction is the construction ministry and [illegible] gas pipes and not be busy with the dead forest [illegible]... It's not our business to preserve [illegible] [illegible]." ([illegible], 1989, p.120)

Tyumen Oblast (see Fig. 2.1) has seen many decades of this industrial onslaught, ever since the first oil fields were opened up in the early 1960s. In 1990, of the 6000 km² of oil and gas fields in the Yamal-Nenets A.O., the total area of destroyed vegetation was 2500 km² and along pipeline routes the figure was 1500 km² (Vilchek & Bykova, 1992, p.105). The pioneers of the West Siberian oil fields and gas fields, quite justifiably in their own eyes, never looked upon their achievements as anything other than heroic, and there is no end to the triumphant references to "new railways cutting through thick forests" or "pipes laid across marshes, endless forests and under big rivers". But the

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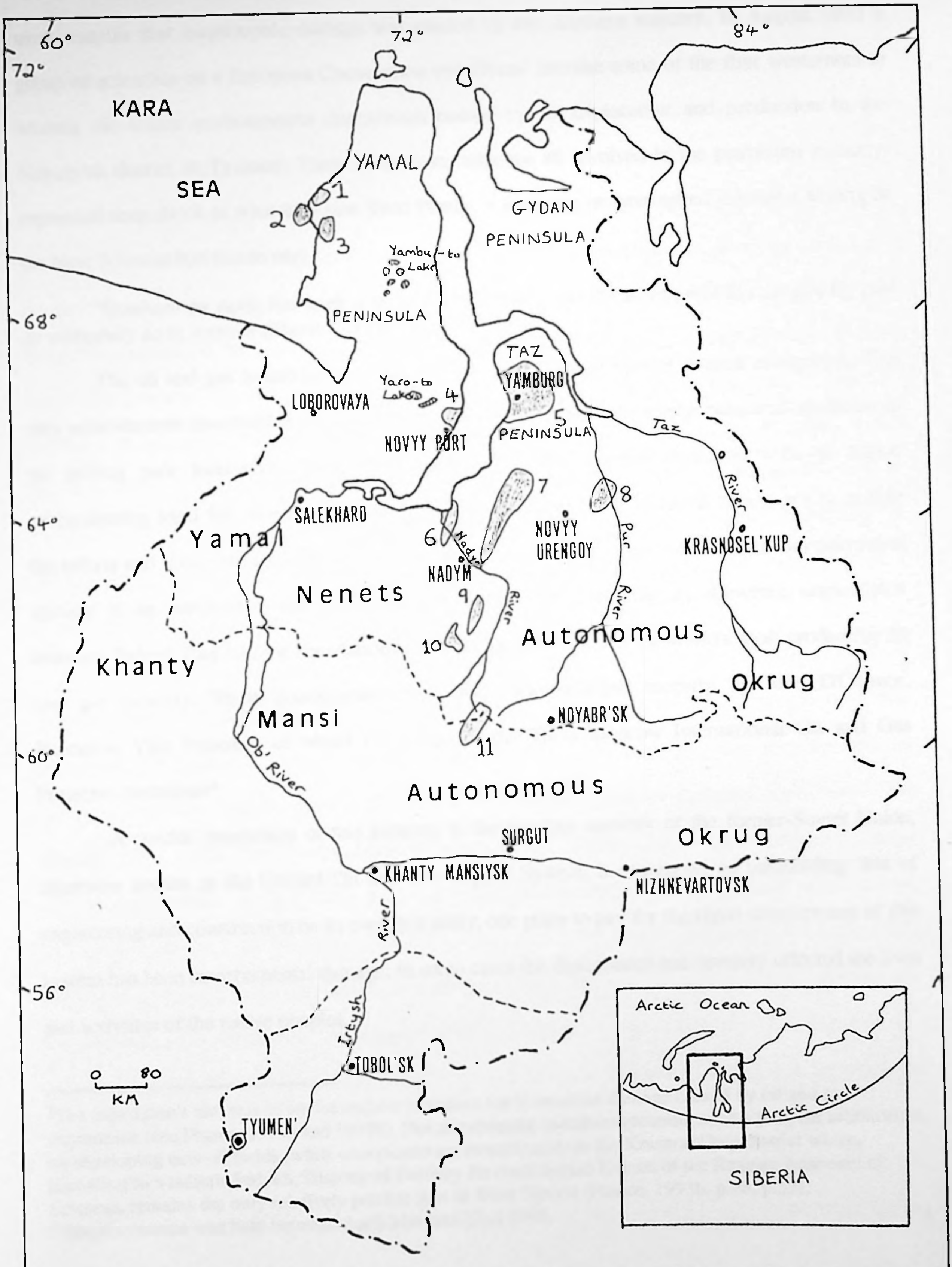
[1] West Siberian natural gas production reached 583 BCM (billion cubic metres) in 1991 (Sagers, 1993, p.[illegible]). [illegible] (1993, p.4) expect an overall increase in West Siberian production of 60-80 BCM per annum.

[2] [illegible], the Ministry of Oil and Gas Construction is [illegible] [illegible] [illegible], the [illegible] of this ministry [illegible].

Figure 2.1 Map of Tyumen' Oblast' showing major gas fields.



GAS FIELDS

1 Kharasaveiskoye
2 Kruzenshternovskoye
3 Bovanenkovskoye
4 Novo-Portovskoye
5 Yamburg
6 Medvezhye
7 Urengoy
8 Zapolyarnoye
9 Gubkinskoye
10 Komsomolskoye
11 Vyngapurovskoye

Figure 2.1. Map of [illegible]

truth remains that catastrophic damage was caused by this northern mastery. In August 1993 a group of scientists on a European Commission expedition[3] become some of the first westerners to witness the severe environmental degradation caused by oil exploration and production in the Noyabr'sk district of Tyumen'. These westerners, who are all involved in the petroleum industry, expressed deep shock at what they saw. Fred Pearce, a freelance environmental journalist writing in the New Scientist had this to say:

"Nowhere on earth has such a large hydrocarbon resource been exploited so quickly and so wastefully as in western Siberia." (Pearce, 1993b, p.28).

The oil and gas industries have left parts of West Siberia scarred beyond recognition. The very achievements described by the industries' pioneers, along with the construction and operation of the drilling pads themselves, have resulted in vast areas becoming inundated with oil slicks, contaminating local fish stocks and depleting reindeer pastures. The intention here is not to belittle the efforts and achievements of these "oilmen", as Lagunov (1982) calls them, for the environmental damage is an unfortunate and unnecessary side-effect of developing an elsewhere unparalleled industry. Indeed, they laid the foundations for what has now become the world's most productive oil and gas industry. These courageous efforts were acknowledged recently by John O'Connor, Executive Vice President of Mobil Oil Corp., at the Third Moscow International Oil and Gas Projects Conference[4].

A crucial component of this industry is the pipeline network of the former-Soviet Union, otherwise known as the Unified Oil and Gas Supply System. It represents an outstanding feat of engineering and construction on its own, but sadly, one price to pay for the rapid development of this system has been environmental damage; in some cases the disturbance has severely effected the lives and activities of the native peoples.

---

[3]The expedition's aim was to advise on how to reduce environmental damage caused by oil and gas exploration (see Pearce, 1993a and 1993b). Not surprisingly, members recommended a ten year moratorium on developing new oil fields (while ecosystems are investigated) in the Krasnosel'kup district which, according to Vladimir Sedykh, Director of Forestry for the Siberian Branch of the Russian Academy of Sciences, remains the only relatively pristine part of West Siberia (Pearce, 1993b, p.28, p.32).
[4]This conference was held between April 21st and 22nd 1994.

[illegible] means that catastrophic damage was caused by this northern invasion. In August 1990 a [illegible] of scientists on a European Commission expedition[illegible] found evidence of the fast withdrawal of [illegible] the severe environmental degradation caused by gas exploration and production in the [illegible] district of Tyumen. These scientists, who are all involved in the petroleum industry, expressed deep shock at what they saw. [illegible] [illegible] writing in [illegible] had this to say:

[illegible] cleaned up [illegible] and [illegible] this.

The oil and gas [illegible] a [illegible] organised corporation. The [illegible] and dismantled of [illegible] [illegible] [illegible] to which [illegible] [illegible] [illegible] [illegible] [illegible] the rest of [illegible] and [illegible] [illegible] [illegible] the world's third [illegible] of [illegible] industry. [illegible] by John O'Connor, [illegible] Van [illegible] of [illegible] [illegible] International Oil and Gas [illegible]

A crucial component of this industry is the pipeline network of the former Soviet Union, [illegible] known as the 'Unified Oil and Gas Supply System'. It represents an outstanding feat of engineering [illegible] but also [illegible] for the rapid development of this [illegible] with environmental damage. In some cases the disturbance has severely affected the lives [illegible] people.

[illegible]

[illegible] between April [illegible] and 22nd 1994

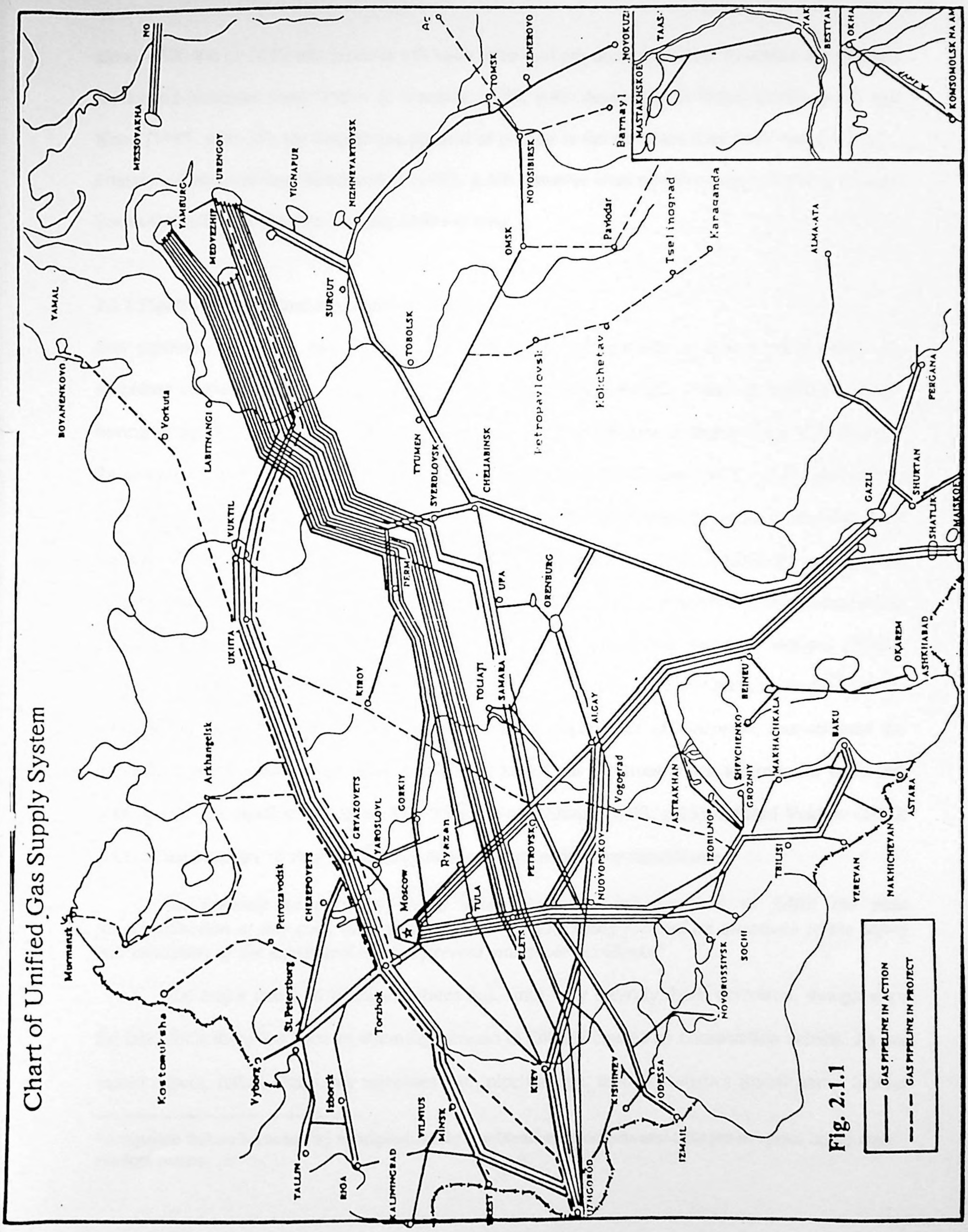
West Siberian oil and gas pipelines have been the cause, either directly or indirectly, of a great deal of environmental damage. Indeed, as Wolfson (1985, p.187) points out, the greatest environmental damage has been caused by transport. The oil pipelines attract most attention because leakages result in liquid emissions which are often sources of serious pollution, and are also very visible. Fortunately, gas pipelines do not contain liquid and so long as leakages are not ignited and they take place in remote areas, there is much less cause for concern. However, detecting them is not so easy. They can normally be made safer by being buried as this greatly reduces the chances of dangerous explosions. But in the permafrost of northern Russia, the burying of an oil or gas pipeline has in fact increased the chances of damage to the pipeline, if not to the environment. In fact, the construction and operation of a pipeline of any configuration, buried, surface-laid, or raised, in the Russian North has caused unique problems. Special construction techniques relevant to the state of permafrozen soils were not used. The Soviets knew of a variety of problems involving the construction and operation of pipelines in such conditions, but due, for example, to the immense cost of putting their research to use, their knowledge was not implemented.

Before examining some cases of serious environmental damage caused by northern West Siberian pipelines, it would be useful to present some statistics regarding Russian gas pipelines. The first trunk gas pipelines were laid during the early 1940s, more than 50 years after the first oil pipelines. The very large-diameter (1420 mm or 56 inch) gas pipelines appeared during the 1970s (Shmal, 1993, p.12). The total length of pipelines in the Unified Gas Supply System (*Yedinaya sistema gazosnabzheniya* or *E.G.S.*), shown in Fig.2.2, is now approximately 225,000 km (Ivantsov, 1993, p.53), of which 64.3% (some 138,400 km) lies within the Russian Federation (Sedykh, 1993, p.65) and 25.4% are 1420 mm (56 in) in diameter (Shmal, 1993, p.12). There are 907 compressor stations with a 50 million kilowatt capacity (Knott, 1993, p.30; Paton & Ivantsov, 1993, p.4) and the 1420 mm pipelines run at pressures of 7.5 MPa (1065 psi). The rate of laying new pipelines has decreased, though in 1991 3500 km of gas pipeline was added. However, in order to realize a 159 BCM growth in gas production between 1995 and 2000, 48,900 km of new gas pipeline must be laid between 1993 and 2000 (Smith Rea Energy Analysts & Infoservice, 1994, p.115). In West Siberia

When Siberian oil and gas pipelines cross lands like tundra, either directly or indirectly, [illegible] a great deal of environmental damage. Indeed, as Wallace (1993, p.102) points out, the greatest environmental damage has been caused by transport. The oil pipelines attract most attention because leakages result in liquid emissions, which are often sources of general pollution, and are also very visible. Fortunately, gas pipelines do not contain liquid and as long as leakages are not ignited and they take place in remote areas, there is much less cause for concern. However, [illegible] is not [illegible]. They use methane [illegible] dangerous explosions. But [illegible] gas pipeline [illegible] it has increased the [illegible]. In fact, the construction and [illegible] Russian North has [illegible] permafrost soils [illegible] construction and [illegible] of putting their [illegible].

Before [illegible] environmental damage caused by transport from Russian pipelines it would be useful to present some information regarding Russian gas pipelines. The first trunk gas pipelines were laid during the early 1940s, more than 50 years after the first oil pipelines. The very large diameter (1420 mm or 56 inch) gas pipelines appeared during the 1970s (Stern, 1993, p.12). The total length of pipelines in the Unified Gas Supply System (Yedinaya sistema gazosnabzheniya or E.G.S.), shown in Fig.2.2, is now approximately 225 000 km (Sagers, 1993, p.53), of which 64.3% (some 138,400 km) lies within the Russian Federation (Sagers, 1993, p.53) and 23.4% are 1420 mm (56 in) in diameter (Stern, 1993, p.12). There are 562 compressor stations with a 50 million kilowatt capacity (Stern, 1993, p.83; Wilson & Ivanov, 1993, p.[illegible]) and the 1420 mm pipelines run at pressures of 7.5 MPa (1085 psi). The rate of laying new pipelines has decreased, though in 1991 3500 km of gas pipeline was added. However, in order to sustain a 45% growth in gas production between 1993 and 2000 45,500 km of new gas pipeline must be laid between 1993 and 2000 (Smith Bio-Energy Analysis & Information, 1994, p.115). In West Siberia

Figure 2.2 Map of the Unified Gas Supply System (*Yedinaya sistema gazosnabzheniya*)
Source: Smith Rea & *Infoservice*, 1993, p.4.



alone, 4500 km of 1420 mm pipeline will have to be laid per annum in order to realize the planned production increases there (Paton & Ivantsov, 1993, p.4). According to Shmal (1993, p.12) and Knott (1993, p.30-31), the longest gas pipeline at present is the 4500 km long 1420 mm Urengoy - Pomary - Uzhgorod line. Korchemkin (1993, p.40) however cites the Yamburg - western former-Soviet Union border pipeline as being 4600 km long.

2.1.2 Pipeline failures and environmental damage

Gas pipelines appear to have been more reliable than oil pipelines in recent years. However, according to Russian sources, both show signs of increasing reliability, with oil pipeline failures[5] having dropped from 81 in 1988 to 53 in 1991 and gas pipeline failures falling from 56 to 43 over the same period (Ivantsov, 1993, p.53). One western source (Hoffmann, 1991, p.11) indicates an increase in the number of oil pipeline breakages since 1985. Clearly, as with all Russian data, statistics on the oil and gas industries should be viewed with caution. Even if gas pipeline reliability is really improving, much work needs to be carried out involving the renovation and replacement of gas pipelines. Indeed, Gennadi Shmal of *Rosneftegazstroy* admits that while oil and gas pipeline reliability may be improving, he cannot say that they are safe (1993, p.14). Aleksandr Sedykh (1993, p.68), Head of the Technical Progress and Ecology Department of *Gazprom*, has stressed the importance of "reconditioning" more than 40,000 km of gas pipelines which are over 20 years old. 5000 km of gas pipelines are more than 33 years old (Shmal, 1993, p.13). Eduard Vekilov (1992, p.43) of the Ministry of Fuel and Energy does try to provide some reassurance:

> *"In contrast to previous years, when the main concern was to fulfill the plan for....production at any cost, increasing attention is now being focused on questions of the safety and reliability of the equipment used to prevent and avoid accidents."*

The major cause of pipeline failures has, until very recently, been corrosion, though since the late 1980s there has been an alarming increase in failures caused by construction defects. As one would expect, failure frequency increases with pipeline age, though statistics reveal many failures

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[5]A pipeline failure is caused by an unpredictable combination of defects and changes in stress, hence their random nature.

during the first six years of operation. This illustrates defects in construction quality control and initial tests that fail to take into account substantial alterations in stresses resulting from changing temperatures when operations begin (Ivantsov, 1993, p.54). Failures have led to a number of serious gas pipeline accidents, perhaps the best known of these being the Ufa explosion in the Bashkortostan Republic in June 1989 which killed 300 and injured 800 in a passing train and caused considerable damage to surrounding vegetation. The causes of this major leakage were supposedly a combination of corrosion, inferior steel quality and construction errors (Rononyi, 1990, p.3). Another emission from a gas pipeline in Orenburg Oblast' in May 1991 caused a serious fire (Ovanesyants *et al.*, 1991, p.112). Northern Russia has experienced a number of accidents, though fortunately these have been less catastrophic in terms of human loss, thanks partly to the sparse population. A serious one was reported in the Taymyr (Dolgan-Nenets) A. O. (Krasnoyarsk Kray) also in 1989, on a 720 mm (28 inch) pipeline which ruptured and exploded. The rupture zone was apparently 40 km in length and considerable damage to the surrounding landscape resulted (Ivantsov, 1993, p.56).

Owing to certain unique characteristics of the Russian North, for instance the sensitive permafrost and indigenous peoples, serious environmental disturbances can occur before the pipeline becomes operational. Considerable environmental damage is caused by the movement of equipment and vehicles involved in the construction of new pipelines, especially when these operations are conducted during summer months. Similar problems occur during the opening up of new fields and drilling sites. The resulting loss of vegetation cover, which is an important insulator, means that during the short summer increased insolation thaws the soil earlier, thus accelerating the thermokarst and solifluction processes, and soil erosion occurs, sometimes on a vast scale. The outcome of this erosion can be the formation of deep gullies and ravines, as shown in Fig.2.3. The degradation is worse in those areas where the soil has a high ice content (Vilchek & Bykova, 1992, p.101). It is hoped that current revegetation trials[6] may soon provide evidence to falsify Vitebsky's statement:

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[6]A considerable amount of effort is being put into revegetation research in Tyumen'. McKendrick & Masalkin (1993, p.5) say that the task "isn't impossible, based on experiences in Alaska's Arctic". Amoco Eurasia are working on this at present and have already collated valuable data from revegetation studies on the Yamal Peninsula (Hardy BBT Ltd., 1991). Younkin & Martens (1994, p.607) conclude a paper with

during the first six years of operation. This illustrates failures in construction quality control and initial tests that fail to take into account substantial [illegible] temperatures when operations begin ([illegible], 1995, p.[illegible]). Such failures have led to a number of serious gas pipeline accidents, perhaps the most known of them being the 1989 explosion in the Bashkortostan Republic in June 1989 which killed 500 and injured 800 in a passing train and caused considerable damage to surrounding vegetation. The causes of this major tragedy were apparently a combination of corrosion, inferior weld quality and construction errors ([illegible], 1993, p.[illegible]). Another explosion from a gas pipeline in [illegible] in May 1995 [illegible] ([illegible] 1991, p.112). Moreover Russia has experienced a number of [illegible] have been less catastrophic [illegible] was reported in the [illegible] the [illegible] pipeline [illegible] and [illegible] (Vilchek & Bykova, 1992, p.[illegible]).

Owing to [illegible] of the Russian North, the [illegible] pipelines and [illegible] environmental disturbances can occur before the pipeline [illegible] operations. [illegible] the environmental damage is caused by the movement of equipment and vehicles involved in the construction of new pipelines, especially when these operations are conducted during summer months. Similar problems occur during the opening up of new fields and drilling sites. The resulting loss of vegetation cover, which is an important insulator, means that during the short summer [illegible] insolation draws the soil earlier, thus accelerating the thermokarst and solifluction processes, and soil erosion occurs, sometimes on a vast scale. The outcome of this is [illegible] on the formation of deep gullies and ravines, as shown in Fig.2.5. The degradation is worse in those areas where the soil has a high ice content (Vilchek & Bykova, 1992, p.[illegible]). It is argued that current re-vegetation trials[illegible] may soon provide evidence to [illegible] [illegible]'s assertion.

[illegible] A considerable amount of [illegible] is being put into revegetation research in [illegible] [illegible] (1995, p.[illegible]) [illegible] "[illegible] impossible", based on experiences in Alaska. [illegible] are working on this [illegible] and have already [illegible]. [illegible] on the [illegible] Peninsula ([illegible] 1995). [illegible] ([illegible], p.[illegible]) [illegible]

Figure 2.3 View of a deep gully cut in sandy soil near the Ob' River.
Source: McKendrick & Masalkin, 1993, p.4.

"A landscape reduced to this condition....will never heal." (Vitebsky, 1990a, p.21).

The severity of these gashes on the northern landscape, shown in Fig.2.4, means that the route becomes impassable and therefore access to the affected region can only be maintained by crossing virgin territory. From the air, one sees vast areas criss-crossed by yellowish tracks left by all-terrain vehicles, the older ones deepened by erosion.

There has been little effort to construct pipelines along pre-existing transport routes, namely supply roads and highways. In the oil fields near Surgut and Noyabr'sk, which straddle the boundary between the Khanty-Mansi and Yamal-Nenets A.O.s, the extent to which pipelines and roads follow

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"Early results strongly suggest that revegetation and seed production in Arctic Siberia is feasible using species developed and raised in North America".

[illegible]

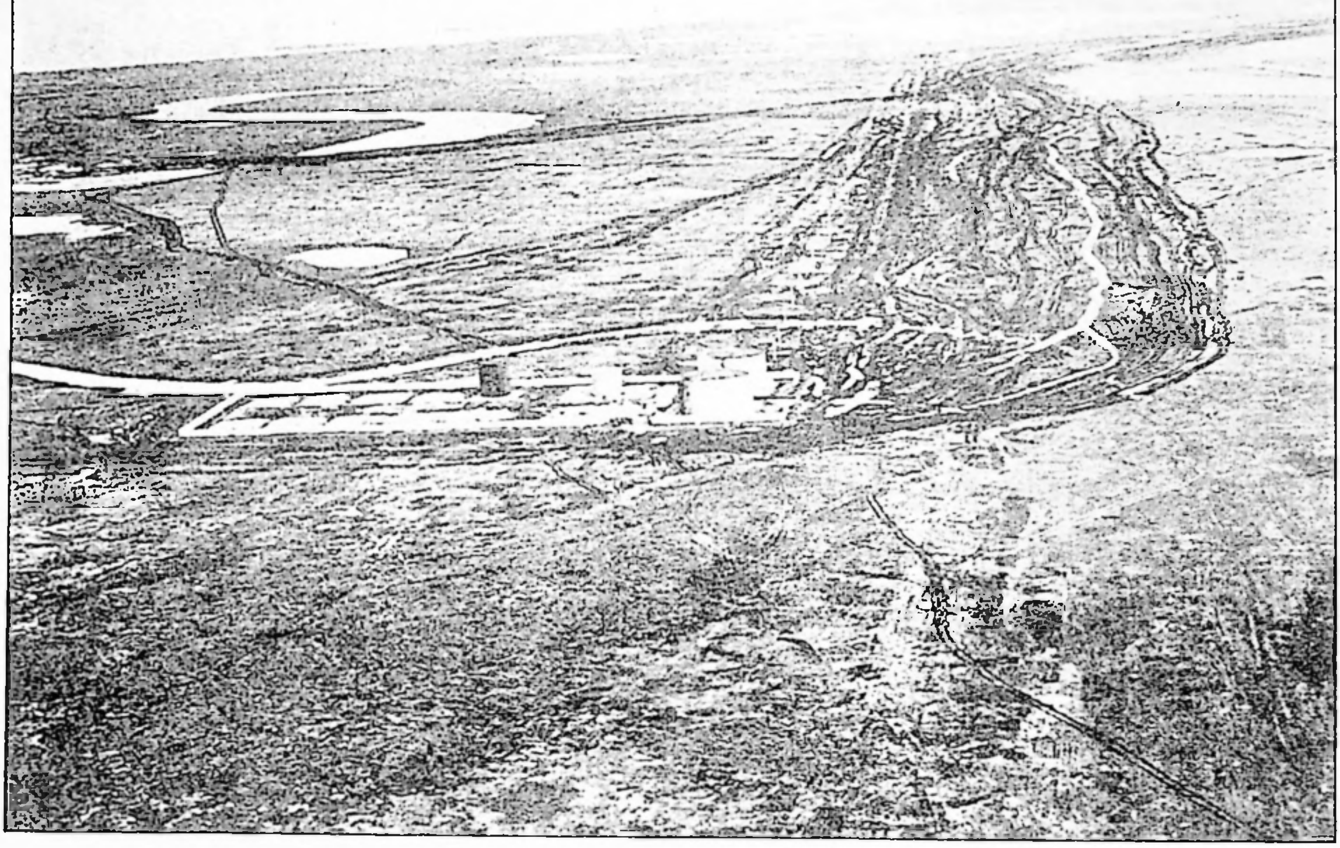
[illegible]

[illegible]

[illegible]

Figure 2.4 Vehicle tracks scar the tundra of northern Tyumen' Oblast'.

a. Numerous vehicle tracks have been deepened through thermokarst formation. Source: McKendrick & Masalkin, 1993, p.5.



b. Vehicle tracks run parallel to a pipeline laid on primitive supports, Tyumen' Oblast'. Source: Peter Williams.

entirely different rights-of-way has led Bob Turnbull of the Institute of Offshore Engineering, Heriot-Watt University, to compare them to spaghetti. Turnbull, a member of the E.C. expedition to Noyabr'sk , said that plans for roads, pipelines, electricity lines and other communications routes are all put together by different people who have no contact with each other. He also said that while pipeline welding and steel quality has improved, "construction techniques are ropy and maintenance, particularly preventative, is non-existent" (Turnbull, 1994). The result of such unnecessary construction techniques is that a much larger portion of the surrounding taiga is damaged. As Vilchek & Bykova (1992, p.101) have said, the transport network of northern Tyumen' is the most damaging for vegetation cover and permafrost. There are however indications that efforts are being made to construct roads and pipelines parallel to each other, but the width of the clearings or "corridors" cut through the taiga when these communications routes are being opened up does seem excessive (Hoffmann, 1991, p.8). These are often 1.5 km wide (Prokhorov, 1989, p.121), with the zone of disturbed soil and vegetation extending much further than this (Vitebsky, 1990a, p.21). A wide corridor with parallel pipelines and roads is nevertheless more favourable from an environmental point of view than the old spaghetti-style construction method.

Another problem caused by pipeline construction in West Siberia has attracted considerable attention both inside and outside Russia. It concerns reindeer (*Rangifer tarandus*), animals that form the basis of the economies of many of Russia's northern native peoples, including the Nentsy of the Yamal-Nenets A.O.. The development of infrastructure necessary for pipeline construction, as well as for the drilling sites, has resulted in widespread loss of valuable pastures. Grounds for rejecting the initial route for the Yamal pipelines included the fact that some 36,000 hectares of pasture would have been lost had the project gone ahead (Pika & Prokhorov, 1989, p.128). With such vast areas of pasture rendered useless, the reindeer are forced to graze in the few areas that remain untouched, for example near Krasnosel'kup. This increase of pressure on pastures inevitably leads to over-grazing and subsequent widespread solifluction (Vilchek & Bykova, 1992, p.105). The pipelines themselves have also interfered with the seasonal migrations of the reindeer. It is said that even if crossing points are incorporated into the pipelines, the reindeer, particularly the females, are disturbed by the noise, entirely different representatives like Ed Bob Turnbull of the Institute of Offshore Engineering, Heriot-Watt University, to compare them to standards. Turnbull, a member of the UK expedition to Noyabrsk, said that plans for roads, pipelines, electricity lines and other communications routes are all put together by different people who have no contact with each other. He also said that while pipeline welding and steel quality has improved, "construction techniques are very bad indeed ... particularly groundwork, is unacceptable" (Turnbull, 1990). The result of such construction techniques is that a much larger portion of the surrounding taiga is disturbed. As Vilchek & Bykova (1992, p.101) have said, the unplanned network of pipelines [illegible] damaging the vegetation cover and permafrost. [illegible] made to construct roads, [illegible] "corridor" [illegible] preceding the [illegible] (Vilchek & Bykova, [illegible]) [illegible] area of disturbed [illegible] [illegible] environmental [illegible] and emphasis on construction method.

Another problem caused by pipeline construction in West Siberia has attracted considerable attention both inside and outside Russia. It concerns reindeer (Rangifer tarandus), animals that form the basis of the economies of many of Russia's northern native peoples, including the Nenets of the Yamal-Nenets A.O. The development of infrastructure necessary for pipeline construction, as well as for the drilling sites, has resulted in widespread loss of valuable pastures. Grounds for rejecting the initial route for the Yamal pipelines included the fact that some 50,000 hectares of pastures would have been lost had the project gone ahead (Vilia & Trofimova, 1990, p.125). With such vast areas of pasture rendered useless, the reindeer are forced to graze in the few areas that remain untouched, for example near Korotchaevo. This increase of pressure on pastures ultimately leads to over-grazing and subsequent widespread salinization (Vilchek & Bykova, 1992, p.102). The pipelines themselves have also interfered with the seasonal migrations of the reindeer. It is said that even if crossing points are incorporated into the pipelines, the reindeer, particularly the females, are disturbed by the noise, making some sections impassable (Vitebsky, 1990a, p.21). However, experiences with the Trans-Alaska Pipeline have shown that the reindeer/caribou pay no attention to the pipeline, let alone noises (as shown in Fig.2.5), and their migrations have rarely been impaired:

"Observations showed that the caribou passed under the elevated pipeline more frequently than over ramps constructed to bridge the pipeline. In addition, they crossed both structures without difficulty, easily gaining access to insect-relief habitat." (BP Exploration (Alaska) Inc., 1991).

It would thus appear that if the relevant measures are taken, pipelines should not obstruct and certainly not prohibit the passage of migrating reindeer, although there is little doubt that problems will occur in the construction phase and that above-ground pipelines would take some years to adjust to.

In Russia's permafrost regions serious environmental damage caused by operating gas pipelines, rather than being a result of one construction worker's mistakes, is often a result of the interactions between the unstable frozen ground and the pipeline itself. In the words of Oleg Ivantsov of *Rosneftegazstroy*:

"The most important feature of northern pipelines, particularly those laid in regions of perennially frozen ground, is their interaction with the natural environment. Here we are talking not only about the effect of technology on the vulnerable northern ecosystem, but also about the negative effect of disruptions of the natural state of the environment on the reliability of the structures themselves." (1993, p.56).

It will perhaps come as a surprise to many, even those only vaguely familiar with the principles of construction in permafrost regions, that until very recently gas had rarely been piped at ground temperature in northern Russia. Warm gas transmission has probably been the cause of numerous gas pipeline ruptures and distortions, resulting in some form of environmental degradation. I will examine this matter in further detail in Chapter 5, but put simply, a warm gas pipeline operating in an area of permafrost will transmit heat to the frozen ground and this will cause the heated area to subside and this may lead to pipeline distortion. Pryanishnikov (1989, p.12) of *Gosplan* acknowledged this fact in his expression of disbelief at the prospect of gas pipeline construction on the Yamal Peninsula. Pipelines that do transport cooled gas have caused the reverse making some sections impassable (Vladislav, 1990, p.21). However, experiences with the Trans-Alaska Pipeline have shown that the caribou/reindeer pay no attention to the pipeline, let alone pylons (as shown in Fig.2.5), and their migrations have hardly been impaired:

"Observations showed that the caribou preferred to cross the elevated pipeline more frequently than over ramps constructed to bridge the pipeline. In addition, they crossed both structures without difficulty, rarely showing notice or stress-related activity." (BP Exploration (Alaska) Inc., 1991)

It would thus appear that if the relevant measures are taken, pipelines should not obstruct and certainly not prohibit the passage of migrating reindeer, although there is little doubt that problems will occur in the construction phase and that those herders and pipelines would take some time to adjust to.

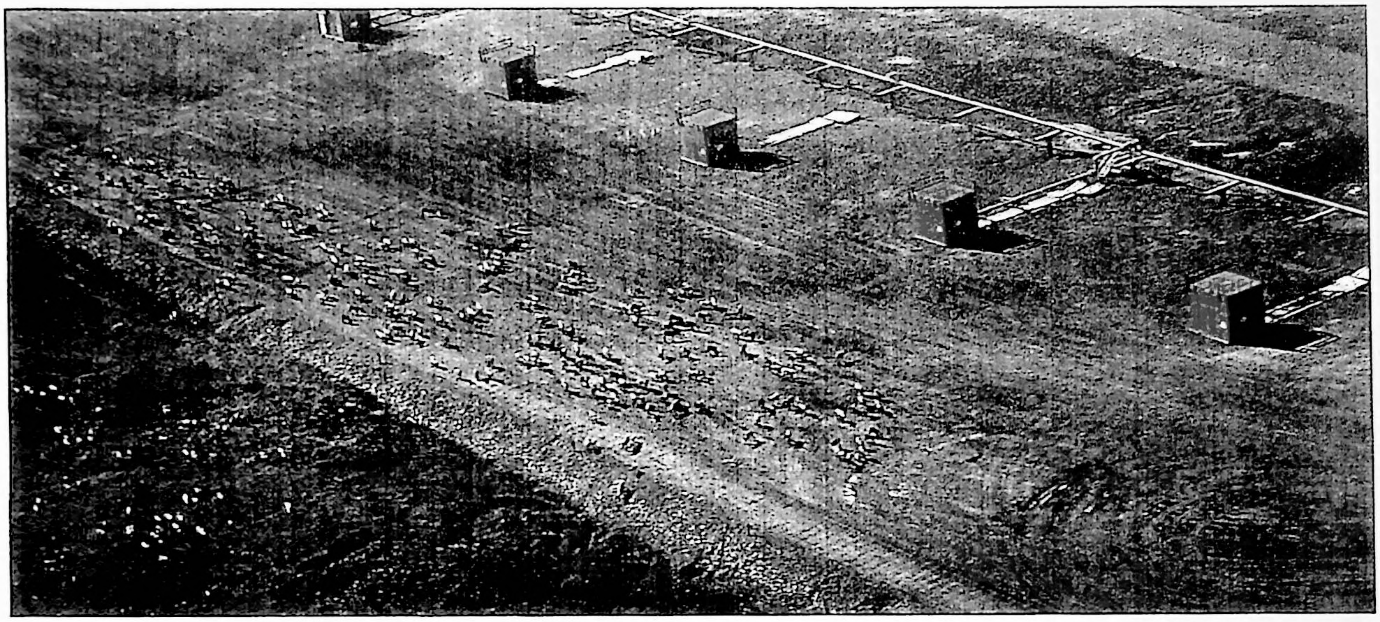
In Russia's permafrost regions [illegible] pipelines, rather than being [illegible] interaction between the [illegible] of permafrost:

"The most important feature of northern pipelines, particularly those laid in regions of permanently frozen ground, is their interaction with the natural environment. Here we are talking not only about the effect of technology on the vulnerable northern ecosystems, but also about the negative effect of disruptions of the natural state of the environment on the reliability of the structures themselves." (1993, p.566)

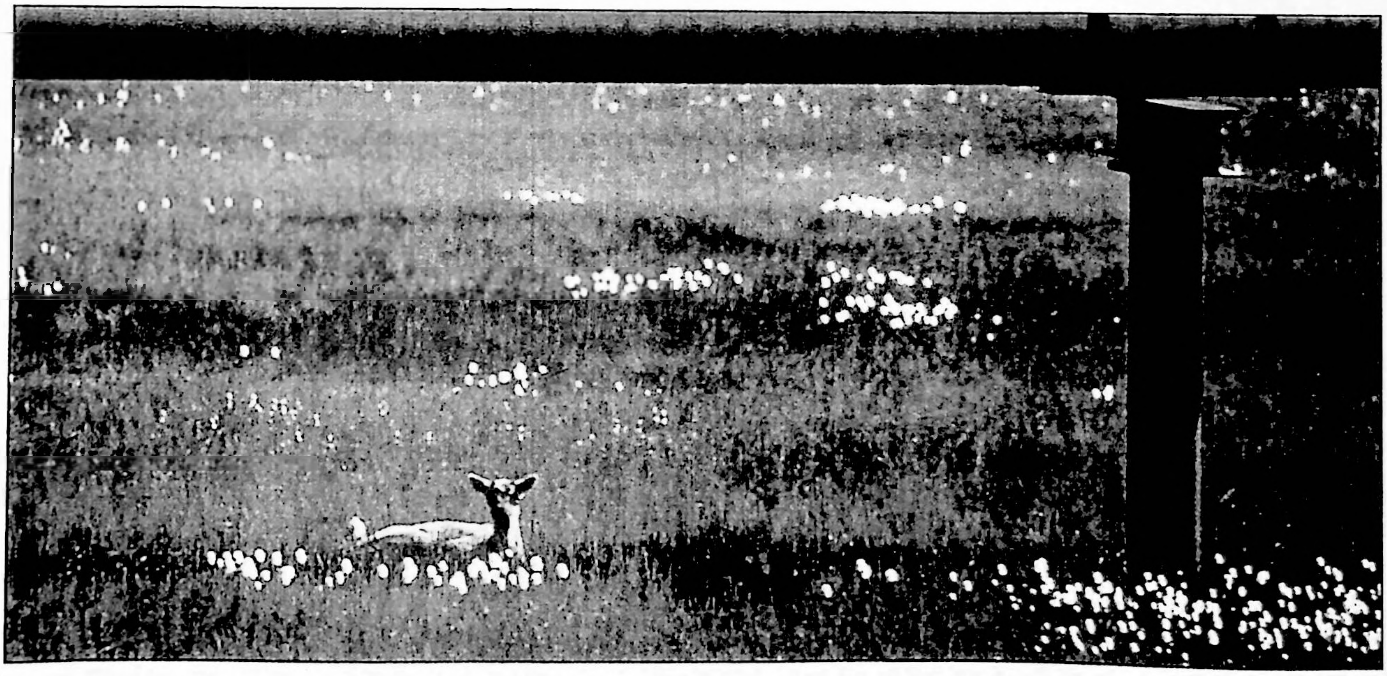
It will perhaps come as a surprise to many, even those only slightly familiar with the principles of construction in permafrost regions, that until very recently gas was rarely ever piped at ground temperature in northern Russia. Warm gas transportation has probably been the cause of numerous gas pipeline ruptures and distortions, resulting in some form of environmental degradation. I will examine this matter in further detail in Chapter 5, but put simply, a warm gas pipeline operating in an area of permafrost will transmit heat to the frozen ground and this will cause the heated area to subside and this may lead to pipeline distortion. Tsvetinskiy (1989, p.13) of Gazprom acknowledged this fact in his expression of doubt at the prospect of gas pipeline construction on the Yamal Peninsula. Pipelines that do transport chilled gas have escaped the adverse

Figure 2.5 Caribou and oil development at Prudhoe Bay, Alaska.

a. Caribou cross a gravel pad. Source: BP Exploration (Alaska) Inc., 1991.



b. A caribou calf rests under a pipeline at Prudhoe Bay. Source: BP Exploration (Alaska) Inc., 1991.



situation, particularly in areas of so-called 'discontinuous' permafrost, where there may be large areas of unfrozen ground. Here, the cooled gas will induce freezing of the soil beneath the pipe and as a result frost heaving, thus pushing the pipeline up and sometimes out of the soil. Evidence of this often takes the form of a pile of soil on top of the entire length of the heaved section, as shown in Fig.2.6. The pipeline has been pushed above the surface and some of the soil covering it has remained on top. Serious distortion like this can rupture the pipe, and since it is now exposed, lead to catastrophic explosions. Cooled gas pipelines can loosen the soil around them and then in summer, when the active layer melts, this loose soil is easily washed away. Fig.2.7 shows that the resulting ditch will deepen over a number of years as the process is repeated every summer (Williams, 1994). An appropriate message comes from B.Prokhorov, an ecological expert who attended a Gosplan conference in 1988 on the construction of a railway and 11 pipelines across the Yamal Peninsula. It serves as a warning to all those contemplating northern pipeline construction projects:

"Inadequate appraisal of local geo-cryological conditions can lead, as has already happened more than once, to the transformation of the pipeline into a continuous, unhealed wound....Sleeping frost can take cruel revenge on those who disturb its peace." (1989, p.116).

It is interesting to note that as a result of the conference, the route of the pipelines was altered in order to avoid having to cross a large section of the peninsula, thus minimizing disturbance to both fragile permafrost conditions and the indigenous peoples and their reindeer. In March 1989 a five year moratorium on pipeline construction in the area was enforced (Vitebsky, 1990a, p.22). With this having passed, a project involving Gazprom and substantial foreign investment is under way with the aim of constructing eight or nine gas pipelines, each 70 km long, across Baydaratskaya Bay, following the route suggested after the conference. The new route makes it unnecessary to cross a vast area of the peninsula and shortens the pipelines by approximately 400 km. The intention is to commence gas supplies in 1997 (Smith Rea Energy Analysts & Infoservice, 1993, p.30). The situation, particularly in areas of so-called 'discontinuous' permafrost, where there may be large areas of unfrozen ground. Here, the cooled gas will induce freezing of the soil beneath the pipe and as a result frost heaving, thus pushing the pipeline up and sometimes out of the soil. Evidence of this often takes the form of a pile of soil on top of the entire length of the heaved section, as shown in Fig 1.6. The pipeline has been pushed above the surface and some of the soil remains on top. Serious [illegible] and [illegible] catastrophic explosions. Cooled gas pipelines can [illegible] the soil [illegible] when the active layer melts, [illegible] Fig. [illegible] shows that the [illegible] will deepen over a number of years [illegible]. An appropriate message [illegible] conference in 1988 on the [illegible] serves as a warning to all those [illegible] pipelines in permafrost:

"Inadequate [illegible] happened more than once [illegible] the pipeline [illegible] ... Stepping [illegible]"

It is interesting to note that as a result of the [illegible], the route of the pipeline was altered in order to avoid having to cross a large section of the peninsula, thus minimising disturbance to both fragile permafrost conditions and the indigenous peoples and their reindeer. In August 1989 a five year moratorium on pipeline construction in the area was enforced (Anisimov, 1990b, p.[illegible]). Soon this having passed, a project involving [illegible] has begun with the aim of constructing eight or nine gas pipelines, each 70 km long, across the [illegible] Bay, following the route suggested after the moratorium. The new route makes it unnecessary to cross a vast area of the peninsula and shortens the pipeline by approximately 400 km. The intention is to commence gas supplies in 1997 [illegible] (Anisimov & [illegible], 1992, p.[illegible]). The

Figure 2.6 Frost heaving and gas pipelines. A large-diameter gas pipeline heaved out of the soil. Clearly visible is the tell-tale heap of soil on top of the heaved section. Source: Peter Williams.

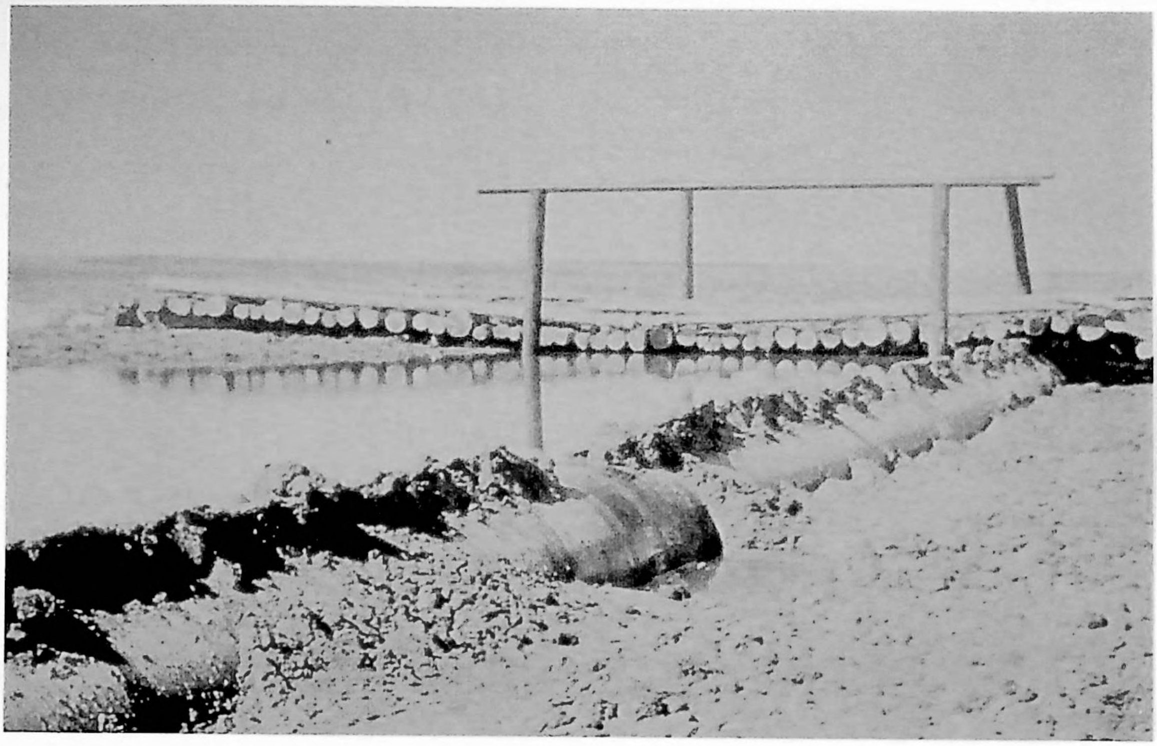
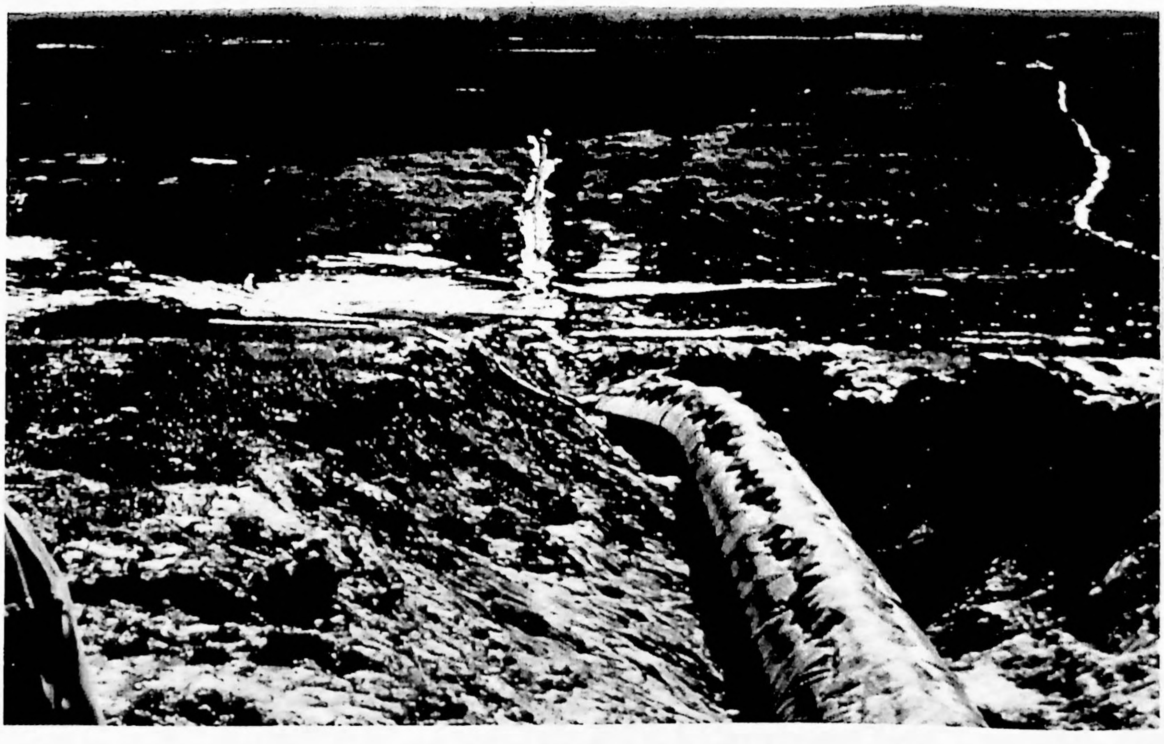


Figure 2.7 Erosion and gas pipelines. A once submerged large-diameter gas pipeline lies suspended and exposed in a gully deepened each summer by erosion. Source: Peter Williams.



opening up of Yamal is a high priority job, since its 25 gas fields[7] contain reserves of 9.3 trillion cubic metres of gas (Sedykh, 1993, p.67).

Gregory Vilchek & Olga Bykova of the Institute of Geography, Russian Academy of Sciences, provide the following summary which demonstrates why northern regions are so susceptible to anthropogenic disturbance:

> *"....simple impacts (mechanical disturbances of vegetation cover and soil, heat injection to the ground....) initiate one or more processes (thermokarst, solifluction, wind erosion, water erosion, fires), which involve significantly larger areas than those primarily disturbed, promoting expansion of the disturbances from the microlocal level to the local one."* (1992, p.101).

2.2 CHANGING ENVIRONMENTAL LEGISLATION FOR THE RUSSIAN OIL AND GAS INDUSTRIES, IN THE CONTEXT OF FOREIGN INVESTMENT

2.2.1 Setting the scene.

Though gas pipeline reliability may well be improving, there is still serious cause for concern. Aged pipelines, with their unreliable compressors, are a constant threat to the surrounding territory and its inhabitants. All-terrain vehicles are used extensively, and it appears that some are being modernized to enhance accessibility rather than to decrease environmental damage. Gas losses through faulty pipelines are tremendously high. Estimates of gas losses vary considerably, but Zavarin (1991) attributed 40% of world gas losses to the former-Soviet Union and Thompson (1994) postulates that nowadays 30% of all hydrocarbons delivered by pipeline are lost during transmission. Along with the maturation of a number of large gas fields, these losses have contributed to a slowing increase in Russian gas production. In 1993, the overall gas production of the Russian Federation actually fell to 618 BCM, from 640 BCM in 1992 (Financial Times, 1994, p.12). But as Korchemkin (1993, p.44) points out, in view of much more significant declines in other sectors of the Russian economy, the recent performance of Gazprom can be considered a success. Oil production continues to decline,

[7]The largest field is Bovanenkovskoye, which has gas reserves of 3.6 trillion cubic metres. This field and Kharasaveiskoye, Kruzenshternovskoye and Novo-Portovskoye fields have been prepared for commercial exploitation.

opening up of Yamal is a high priority job, since its 25 gas fields[1] contain reserves of 9.5 trillion cubic metres of gas (Sedykh, 1995, p.67).

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"...simple impacts (mechanical disturbance [illegible] of the ground,...) initiate one or more processes ([illegible]), which involve significantly larger [illegible] expansion of the disturbances from the [illegible]" ([illegible])

2.2 CHANGING INVESTMENT IN EXPLORATION FOR THE RUSSIAN OIL AND GAS INDUSTRIES: [illegible]

2.2.1 Setting the scene

Though gas production [illegible] may avoid the most [illegible] pipelines, with their associated [illegible] are a constant threat to the environment, to industry and its inhabitants. Alternative methods are used extensively, and it appears that more are being introduced to enhance accessibility rather than to decrease environmental damage. Gas losses through leaky pipelines are tremendously high. Estimates of gas losses vary considerably, but Zavarin (1993) estimated 40% of world gas losses to the former-Soviet Union and Thompson (1994) postulates that some 30% of all hydrocarbons [illegible] are lost during transportation. Along with the exhaustion of a number of large gas fields, these losses have contributed to a slowing increase in Russian gas production. In 1993, the overall gas production in the Russian Federation actually fell to 618 BCM, from 640 BCM in 1992 (Financial Times, 1994, p.17). But as Kryukov (1994, p.46) points out, in view of much more significant declines in other sectors of the Russian economy, the recent performance of Gazprom can be considered a success. Oil production continues to decline

[1] The largest field is Bovanenkovskoye, which has gas reserves of 3.6 trillion cubic metres. This field and Kharasaveiskoye, Kruzenshternovskoye and Novoportovskoye fields have been prepared for commercial exploitation.

though at a less drastic rate than in recent years. According to Sergey Bourtsev[8] (1994a, p.293) of the Ministry of Environmental Protection and Natural Resources, the 1993 output was not expected to exceed 340 million tons, compared to a 1992 output of 394 million tons. Perhaps most relevant to this thesis, international cooperation in the form of joint-ventures and production-sharing agreements is emerging. A number of so-called megaprojects worth billions of dollars and involving four or five western multinationals are nearing implementation phase. The Sakhalin "MMMMS" project[9] is attracting much attention since it is likely to become a blue-print for further megaprojects once arrangements have been finalized and development of oil and gas fields begins.

Since the collapse of the Soviet Union in 1991, the oil and gas industries have experienced highly significant changes, the most important of these being the division of the oil and gas industry into separate sectors. The oil industry is now dominated by four large holding companies which have been privatized - *Rosneft*, *Yukos*, *Lukoil*, *Surgutneftegaz*[10] - and are now the world's largest oil production enterprises. *Gazprom*, the state gas monopoly, is now a joint-stock company, the world's largest gas company, and is being privatized. It remains far more centralized than the oil sector (Volchkov & Prusenko, 1994, p.196) and is the last Soviet-type giant to survive. Under the Russian government's Decree No.1333, 28.7% of *Gazprom* shares are to be sold to the residents of those regions in which it operates (Korchemkin, 1993, p.40). It recently announced that 5.2% of its shares would be made available to the native peoples of the Yamal-Nenets A.O., which is to become Russia's major gas supply region[11], and up to 10% of the shares will be offered to foreign investors

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[8]Bourtsev has been mis-transliterated. The name should be Burtsev (as in Burtsev, 1994b). Bourtsev (1994a) has been retained since the original document uses this spelling.

[9]Known as "Sakhalin-2", this $10-12 billion project involves the development of the Piltun-Astokhskoye and Lunskoye oil and gas fields by Marathon, McDermott (U.S.A.), Mitsubishi, Mitsui (Japan) and Royal Dutch Shell. Oil and gas pipelines and an LNG plant will be built. In order to avoid legal controversies, the consortium established Sakhalin Energy Ltd. (SE) on April 18th 1994 which will be the operator company. The Production-sharing agreement should have received final approval by mid-May 1994 (*Russian Petroleum Investor*, 1994b, p.58, 62).

[10]*Rosneft* holds the state interest in all production, refining and distribution enterprises, while *Yukos*, *Lukoil* and *Surgutneftegaz* are integrated companies (Stern, 1993, p.19).

[11]Yamal gas will also be exported to Poland and Germany through a 5500 km pipeline. Poland will receive approximately 150 BCM per annum (Pipeline & Gas Journal, 1993b, p.1). The pipeline system could cost up to $10 billion (Pipeline & Gas Journal, 1993a, p.4).

(Boulton, 1994a, p.3). Both sectors are desperately trying to attract foreign investment in order to help revive these two ailing giants. To achieve this, they need to change their environmental images entirely, particularly in view of privatization. As Aleksandr Sedykh of *Gazprom* has stressed, the opening up of new fields in such frontier regions as the Yamal Peninsula and the Sakha Republic:

"....demands a non-traditional approach to decision-making...." (1993, p.67).

So the question remains; in the light of foreign investment and a trend towards the opening up of new and very remote oil and gas regions, what is being done about this? After so many years of environmental neglect, can a policy reversal of such massive proportions become a reality? How is the West Siberian legacy to be avoided in the future?

2.2.2 Radical policy changes.

Russian delegates at two recent conferences addressing various aspects of oil and gas production and exploration were able to discuss matters that a decade ago would have been impossible even to contemplate. The following extracts from their respective presentations will demonstrate the degree to which environmental concerns were neglected during the Soviet era. Regarding the former Soviet Union's legislative basis for ecological safety in the oil and gas industry, S.Volchkov and B.Prusenko of the Gubkin Federal Academy for Oil and Gas, attending the Second International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production[12], asserted that:

"....there were very few laws devoted to....ecological safety." (1994, p.194).

They went on to say:

"The issues in the field of....environmental safety were not of the (sic) primary attention for various key officials", and *"The top level of....environmental safety was formally (sic) the level of chief engineers.* (1994, p.195).

[12]Held in Jakarta, Indonesia, 25th to 27th January 1994.

At the same conference V.Estratov of *GiproFyument Neftegaz* and colleagues from Shell examined this issue further. They revealed that in the early days of conducting Environmental Impact Assessments (EIAs), or OVOSs as they are called in Russia[13],:

"....assessments were generally carried out by technologists, not ecologists. EIA was seen as a technical issue, in which biologists could (or could not) have an input. As a result, intrinsic ecological values and environmental sensitivities have not always been sufficiently identified..... A multi-disciplinary approach, required for a systematic analysis of environmental issues, has not been a part of the Russian methodology." (Geerling *et al*, 1994, p.125).

Regarding the old centralized oil and gas ministries, their overall message was:

"In the past, there has been no comprehensive environmental management approach in the Russian industry." and *"The institutional position of an EIA was....designed to obtain permits, and it was never considered a living document, or a part of any development or management process."* (Geerling *et al*, 1994, p.124).

At the Third Moscow International Oil and Gas Projects Conference, senior members of *Lukoil*, *Gazprom* and the Ministry of Environmental Protection and Natural Resources among others did not hesitate to admit such shortcomings. At the top of their agenda was the task of reassuring potential foreign investors, both the multinational oil and gas companies and the money-lenders, that their desire to remedy a blackened past is sincere and that the wholesale restructuring of the environmental legislation for oil and gas exploration and production is well on its way to producing tangible results.

Firstly it should be said that during the transitional period, economic, political and legal matters are of primary concern. Environmental concerns, and other matters of secondary importance, have to take a back seat for the time being. In spite of such delays in the legislative approval process, significant progress is being made with the implementation of new environmental legislation, particularly that concerning JVs (joint-ventures) and PSAs (production sharing agreements) in oil and gas exploration and production and related activities (for example, pipeline construction). Fuelling this trend are high expectations of western wealth and environmental expertise. Nevertheless, as both Bourtsev (1994a, p.296) and Volchkov & Prusenko (1994, p.195) hasten to

[13]The formal procedure of carrying out environmental impact assessments in Russia began during the late 1980s (Bourtsev, 1994a, p.295).

add, the existing legislative structures are not adequate. After all, without solid environmental legislation and accompanying policies, potential foreign investors will be reluctant to initiate negotiations for exploration, production and construction projects within the Russian Federation. Clearly, legislative remediation is crucial, particularly since, in the words of Bourtsev:

"No revival of Russian oil and gas industry is possible without active participation of foreign companies and investments." (1994a, p.293).

A major landmark in the development of Russian environmental legislature was the approval by parliament of the "Law on Environmental Protection" in March 1992. It contains 94 articles and, specific to oil and gas production, prescribes environmental requirements for the siting, design and operation of a facility or enterprise. Also included are Standards, Construction Norms and Rules (SNIPs) which have a similar role and exist for pipeline construction regulation for instance. However, L.A.Dimov of the industrial science firm *Taleon* and *VNIIPKspetsstroykonstruktsiya* (Ukhta branch, Komi Republic) criticizes the SNIPs in two recent articles (1993a, p.16-18; 1993b, p.13-15). He maintains that those concerning northern pipeline planning and construction are too vague and are not supported by sufficient scientific research.

Another major inadequacy of the law is that it does not mention Environmental Impact Assessments (EIA) and thus an EIA is not yet a mandatory procedure in Russia, although Oil & Gas Journal has reported "a pending environmental impact assessment law" (1993, p.31). The Russians have nevertheless developed an EIA procedure, for which there are a number of rigid guidelines, for example the requirement to specify capital investment and operational expenditure regarding conservation measures (Geerling *et al*, 1994, p.125). The Russian EIA is based fundamentally upon western laws and international conventions and directives, for example EEC Directive 85/337 (Bourtsev, 1994a, p.296) and, contrary to the old centralized philosophy, a multi-disciplinary approach is applied when the EIA is carried out. Geerling *et al*, provide an example of this approach, drawing from recent Shell experience of oil field development in West Siberia:

"TERM, a....design institute from Tyumen', drew up an environmental impact statement.... This material was then used for the final document, which was based on Shell standards of

als, the existing legislative structures are not adequate. After all, without sound environmental legislation and accompanying policies, potential foreign investors will be reluctant to commit resources for exploration, production and construction projects within the Russian Federation. Clearly, legislative consolidation is crucial, particularly [illegible] Bradshaw:

"The revival of Russian oil and gas industry is [illegible] without making partial openings of foreign companies and investments." (1994b, p.203).

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Another major inadequacy of the law is that it does not mention Environmental Impact Assessments (EIAs) and thus an EIA is not yet a mandatory procedure in Russia, although [illegible] has reported "a pending environmental impact assessment law" (1993, p.73). The Russians have nevertheless developed an EIA procedure, for which there are a number of rigid guidelines, for example the requirement to specify capital investment and operational expenditure regarding conservation measures (Cowling et al, 1994, p.125). The Russian EIA is based fundamentally upon Western laws and international conventions and directives, for example 1985 Directive 85/337 (Bradshaw, 1994b, p.208) and, contrary to the old centralised philosophy, a multi-disciplinary approach is applied when the EIA is carried out. Cowling et al. provide an example of this approach, drawing from recent Shell experience of oil field development in West Siberia:

"TEEM, a Russian institute from Tyumen', drew up an environmental impact assessment. This material was then used for the final document, which was based on Shell standards of

environmental management, but in a format stipulated by the Russian authorities. Field work was carried out by both Shell environmental specialists and local institutes on behalf of the company.

In this way, a maximum of local knowledge and expertise was incorporated into the environmental assessment. Local concerns, cultural aspects and the appropriate presentation are taken into account." (1994, p.126).

This kind of cooperative pooling of foreign expertise and local knowledge is crucial to the realization of any oil and gas development project, particularly within relatively unindustrialized frontier regions of Russia such as the Sakha Republic.

The Law on Environmental Protection does however enforce the State Environmental Review (SER) procedure, which was inaugurated in 1988. Like the EIA, SERs are made by an interdisciplinary team of specialists from academic institutions and various agencies. Financing and construction activity for any proposed JV of a value in excess of $100 million cannot be initiated until a positive decision has been made by the State Environmental Review Commission, under the Ministry of Environmental Protection and Natural Resources, after the feasibility study has been examined. If this rule is not observed, large penalties and even criminal responsibilities can be incurred (Amirkhanov, 1994). In 1992, more than 55,000 reviews were carried out for both Russian and foreign projects. In 1993, more than 75,000 were conducted (Burtsev, 1994b). Burtsev claims that feasibility studies for economic development in northern Russia and on continental shelves are reviewed most critically. Recent SERs included those for the "MMMMS" Consortium offshore Sakhalin oil and gas exploration and production project; the "Arctic Star" JV for exploration in the Shtokmanovskoye gas field in the Barents Sea; and the "Polar Lights" JV of Conoco and *Arkhangel'skgeologiya* in the Nenets A.O. (Arkhangel'sk Oblast'). All JVs involving less than $100 million must be registered and reviewed at a local level.

It is interesting to note that the standard of feasibility studies carried out by foreign oil and gas companies has apparently not been up to Russian expectations:

"Feasibility studies presented by western companies do not correspond to the requirements of the rules and standards effective on the Russian territory.... Most projects cannot serve as economic and environmental substantiation of JV's intentions to develop oil fields for they usually lack information on technical solutions and proposals. Documents are overfilled with data not related directly to the project and at the same time they can be vague and insufficient concerning the current state of the environment, actual changes and destruction of nature....

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In this way, a minimum of local knowledge and expertise was incorporated into the environmental assessment. Local concerns, cultural aspects and the appropriate mechanisms, [illegible] taken into account." (1994, p.129).

This kind of cooperative pooling of foreign expertise and local knowledge is crucial to the evaluation of any oil and gas development project, particularly within relatively undisturbed [illegible] remote regions of Russia such as the Sakha Republic.

The Law on Environmental Protection [illegible] requires the State Environmental Expert Review (SEER) procedure, which was institutionalized [illegible] a [illegible] sum of specialists [illegible] construction activity for any proposed [illegible] and a positive decision has been made [illegible] Ministry of Environmental Protection [illegible] obtained. If that [illegible] banned (Anisimov, [illegible]) [illegible] and foreign investors. In 1993, more than 75,000 were conducted [illegible] the feasibility studies for economic developments in particular [illegible] reviewed most critically. Recent SEERs included those for the "[illegible]" Consortium [illegible] Sakhalin oil and gas exploration and production project, the "[illegible]" JV for construction in the [illegible] gas field in the [illegible] Sea, and the "[illegible]" JV of Conoco [illegible] [illegible] in the Nenets A.O. (Anisimov, [illegible]). All JVs involving [illegible] million must be registered and reviewed at a local level.

It is interesting to note that the standard of feasibility studies carried out by foreign oil and gas companies has apparently not been up to Russian expectations.

"*Feasibility studies presented by western companies do not correspond to [illegible] requirements of the rules and standards effective on the Russian territory.... Most projects [illegible] none of economic and environmental substantiation of JV's intentions to develop oil fields for [illegible] usually lack information on technical solutions and proposals. Documents are overfilled with [illegible] not related directly to the project and at the same time they can be vague and [illegible] concerning the current state of the environment, actual changes and destruction of [illegible]*

Documents do not contain information on risk analysis and evaluation of the environmental effects of emergency situations."

Specific to northern Russia:

"Many legislative requirements on protecting the environment and the rights of small ethnic groups of the North are simply ignored in many documents.... Very often expert commissions state that materials presented for their consideration do not sufficiently take into account the....environmental standards and rules for construction in the Arctic." (Bourtsev, 1994a, p.298-299).

Accusations like these have led certain review commissions to request a revamped feasibility study from foreign companies. It is not without justification that Amir Amirkhanov (1994), Deputy Minister of Environmental Protection and Natural Resources, says that many environmental standards in Russia are higher than those of their western counterparts, though these standards vary between industry, project and region. He believes that standards will continue to rise. In general, according to Amirkhanov, if certain international standards are higher than their equivalents in Russian, these will be adopted.

As far as technology transfers to the C.I.S. are concerned, Bourtsev (1994b) says that in the past some equipment arriving has been obsolete. Therefore, western companies are now required to submit certificates verifying the origin and reliability of new technologies.

The involvement of experts from many different scientific and sociological disciplines in reviews and EIAs reflects a marked change in the position held by the indigenous peoples in respect to economic activity. They have statutory rights over large territories and any proposed development activity, including oil and gas exploration and production, requires their approval. The indigenous peoples of Siberia and the Russian Far East are now only too willing to fight for rights to ancestral lands and hunting territory, as well as in other matters. As Burtsev (1994b) points out, failure to acknowledge the demands of the indigenous peoples has led to conflict, particularly in cases where exploitation actually got under way. A good example is the recent case of the Udege of Primor'ye Kray in the Far East, where forests along the Bikin River were being felled by the South Korean firm Hyundai Group. Early in 1993, Russia's Supreme Court ruled against the JV on the grounds that the logging operation was infringing upon the land of indigenous peoples (IWGIA, 1993, p.37). It is

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We are now seeing a trend towards the advocacy of accelerated JV and PSA oil and gas development whilst remarkably high environmental standards and concerns for the well-being of indigenous peoples, particularly in northern Russia, are becoming central components of development strategies, so much so that environmental requirements for domestic firms appear relatively lenient. The Russians are now looking for deep commitment to environmental and human preservation from all potential foreign investors. According to Bernhard Metzger of Arthur D.Little Inc. (ADL) consulting company:

"To be successful in the C.I.S., western industries must be sensitive to local customs and cultural idiosyncrasies, ready for sudden political changes, and responsive to evolving rules." (Oil & Gas Journal, 1993, p.31).

In spite of this complete policy turnaround the overall picture is unclear and change in legislative procedures remains unpredictable. Potential foreign investors are at present reluctant to seize hold of the unparalleled opportunities in the Russian (and C.I.S.) oil and gas sectors. The situation is unlikely to change until environmental legislation concerning oil and gas activities has

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[14]Local administrations at oblast', okrug and rayon level, included very few indigenous representitives. The situation is beginning to change now, particularly in areas such as the Sakha Republic.

been entirely renovated, new environmental laws and regulations (for example enforcing EIAs) appear and, as Robert Starr (1994, p.167) of the international law firm Salans, Hertzfeld & Heilbronn points out, overlapping jurisdictional assertions at central, regional and local level have been clarified. All this must accompany the development of a sound taxation system, export policies and insurance arrangements for foreign investors. Clearly, the required clarifications will take time, perhaps years, to materialize. But the Russians are necessarily committed to producing these results. By working with the west[15], the day may arrive when Russia can be declared a safe operating environment for foreign companies wishing to become engaged in oil and gas development projects on all scales.

At the time of writing, measures to enhance foreign investment within the Russian energy sector were being introduced as part of efforts to revive economic reform. For example, the financial Times reported that President Yeltsin had:

"....scrapped quotas and licenses for oil and gas exports from July 1st [1994] and offered a three-year tax holiday to foreign investors...." (Boulton, 1994b, p.2).

This move represents acknowledgement by Russia of domestic and foreign economists' calls for the lifting of "antiquated controls on its lucrative energy exports".

Tax concessions have also been granted recently. The Times reported:

"The Russians....conceded ground on royalties, profits and tax hurdles that had delayed negotiations." (*Times*, 1994, p.36).

These have been particularly helpful for on-going negotiations concerning the Sakhalin-2 project.

[15]The European Commission has just released a report on law reform in the C.I.S. which details a strategy for law reform assistance and suggests minimum quality standards for extending such assistance (Butler, 1994, p.9).

Chapter 3

Natural Gas in the Sakha Republic

3.1 THE DEVELOPMENT OF THE NATURAL GAS INDUSTRY

3.1.1 The early years.

Hydrocarbons have been known to exist in the Sakha Republic for many centuries. The naturalist Johann Georg Gmelin, who travelled through Siberia and the Soviet Far East between 1733 and 1743, described a bad-smelling, thick, dark and inflammable liquid which spotted the surface of the Vilyuy River basin (Alekseyev, 1989, p.59). The local shamans would use "burning water" to cure patients, while friends and relatives looked on in awe. These shamans could never have known that one day this burning substance would serve entirely different purposes. Likewise, they would not have been aware that their homeland was laden with this substance (as is the case with so many other natural resources).

With the first indications of potentially exploitable hydrocarbons, prospecting for oil and natural gas in the republic began in 1932, but due to the remoteness and difficulties involved in moving around the region, progress was extremely slow. However, after the establishment of the state geophysical company *Yakutskgeofizika* in 1950, exploration began to bear fruit. Highly significant discoveries were made in the late 1950s and early 1960s. The first gas field (Ust'-Vilyuyskoye) was discovered in 1956 at Taas-Tumus near the mouth of the Vilyuy River (Shabad, 1969, p.40), and in 1965 the Tolon-Mastakhskoye field, also in the Vilyuyan region, was discovered and at that time reputed to be the largest in the republic (Shabad, 1973, p.478). In 1961 the first field in the Nepa-Botuobian region was discovered at Markovo, several hundred kilometres to the south west (Thompson, 1994). The Vilyuyan and Nepa-Botuobian regions represent the two storehouses of the republic's hydrocarbon wealth and they will be discussed in more detail below.

Natural gas production began in 1967 with the completion of the Taas-Tumus - Yakutsk pipeline[1] (Intera & *Sakhaneftegaz*, 1993) and this was followed by the opening in Yakutsk of the first 25,000 kilowatt section of a 100,000 kilowatt gas-turbine station in early 1970 (Shabad, 1970, p.294). By 1972, Bakhanov (1972, p.1) reported that only one well per 31,000 km² or 318,000 m of deep well had been drilled, but the following year an important landmark was passed when the first CDP seismic data was obtained by *Yakutskgeofizika*. A major breakthrough had nevertheless been made in 1971 with the discovery of eight large gas and gas condensate fields. This led scientists to declare that Sakha's natural gas stores were not inferior to the immense deposits of West Siberia, where most of the prospecting work was concentrated. Academician Abel Aganbegyan was to say in an interview in 1984 that:

> *"Yakutia's chief resources....are petroleum and gas. A vast oil and gas province is located there. I have no doubt that Yakutia will become one of the major regions of petroleum and gas extraction by the end of the century."* (Konovalov, 1984, p.2).

Even today it is impossible to discount Aganbegyan's suppositions. The chief aim at present is to quantify and qualify the republic's natural gas reserves. This must be achieved as soon as possible because it represents the first step towards the possible development of natural gas for export purposes. Many in the Northeast Pacific Rim (an emerging market for natural gas, particularly LNG), and beyond, will be hoping that Aganbegyan's forecast becomes reality, although it can be confirmed at this stage that large-scale exports will not commence until well into the next century (Thompson, 1994).

3.1.2 The gas industry nowadays.

In 1992 the government of the Sakha Republic established *Sakhaneftegaz*, the state oil and gas (joint-stock) company, which encompasses geophysical, geological, production and trading companies in the oil and gas sectors. The company has inherited considerable recoverable gas reserves: approximately 1.3 TCM (categories $A+B+C_1+C_2$ [2]) at 1st January 1993 (Intera &

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[1]Gas transport infrastructure will be discussed in detail in a following section.
[2]See Appendix 1 for an explanation of these categories.

Sakhaneftegaz, 1993), though these are far less than the estimates of possible reserves. The progress of the oil and gas industry, for example geophysical work, and like all development in the republic has been extremely slow. This can be attributed chiefly to the following two factors; the first is derived from Russia's extremely complex hierarchical political structure which, in the Sakha Republic's case, is perhaps more complex than ever before, while the second, as already mentioned, is derived from regional physical peculiarities.

On the one hand is the disruption to every aspect of Yakut society caused by the disorganization and confusion that epitomizes this republic. It is theoretically independent (the Constitution of the Sovereign Sakha Republic having come into force in April 1992) but is still very much in the grips of the Russian Federation, which is undergoing an erratic transitional period from Communism to Capitalism. This is clearly illustrated in the following fact. In an unprecedented move, the Russian Federation will soon stipulate that all natural resources, including oil and gas, are once again to become the sole property of the Russian Federation (Amirkhanov, 1994). This represents a reversal and complete rejection of Article 5 of Sakha's constitution which states that:

> *"The earth and mineral resources, water, forests, wildlife and other natural resources, air and continental shelf of the Republic is the integral property of the people of the Republic of Sakha (Yakutia)."*

Amir Amirkhanov justifies this decision by saying that Article 5 was "unreasonable" in the first place. His reasoning lies in the fact that the republic is still very much reliant upon other regions of the federation for numerous consumer products, not to mention oil products. This means that in fact Sakha is not truly independent since it remains a subject of the Russian Federation. Thus it is not in a position to manage its resources single-handedly.

On the other hand lie the republic's physical peculiarities and extremes. An extremely harsh continental climate and resulting permafrost conditions have hindered all oil and gas activities in the republic. The vast distance[3] from the "centre" and the major consumption zones of the European

[3]Yakutsk lies some 5000 km to the northeast of Moscow.

[illegible] 1993), though these are far less than the estimates of possible reserves. The progress of the oil and gas industry, for example geophysical work, and the oil development in the republic has been extremely slow. This can be attributed mainly to the following two factors: the first is derived from Russia's extremely complex hierarchical political structure which, in the Sakha Republic's case, is perhaps more complex than ever before, while the second is directly connected with regional physical parameters.

On the one hand is the [illegible] reduced by the [illegible] and [illegible] of the Sakha Republic [illegible] grip of the Russian [illegible] the Russian Federation [illegible] and went so far as to become the [illegible] Sakha's Constitution (Konstitutsiya, 1992). This [illegible] Article 5 of Sakha's constitution which states that:

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On the other hand lie the republic's physical peculiarities and remoteness. An extremely harsh continental climate and resulting permafrost conditions have hindered oil and gas activities in the region. The vast distance[?] from the "centre" and the major consumption areas of the European

[illegible] lies some 5000 km to the northeast of Moscow.

Core has meant that Sakha has never been a region destined for priority development. Exploration and production have traditionally focused upon West Siberia's Tyumen' Oblast'.

The constraints imposed by these factors upon the republic's immature oil and gas industry are reflected in the production statistics for the republic. Gas production from five fields amounts to only 1.5 BCM per annum, and there is no commercial exploitation of oil fields (Intera & *Sakhaneftegaz*, 1993), though minor oil and gas condensate production began recently in the Nepa-Botuobian region. For this reason, 2 million tons of oil products are imported annually. The gas is used to keep Yakutsk and Mirnyy warm in winter, as well as a number of smaller settlements, and to keep industry operational. With a poorly developed industry and infrastructure, as well as financial and material constraints, and with estimated recoverable gas reserves of 14.2 TCM, it is easy to see why the republic proposes to attract foreign investors into a variety of oil and gas projects (foreign involvement in the development of the republic's natural gas will be examined in section 3.3).

The oil and gas potential of the Sakha Republic is great. Intera & *Sakhaneftegaz* (1993) maintain that the prospective area for oil and gas in the republic covers 1.64 million km² (half of the republic's total area), the vast majority of which lies on the Siberian Platform (see Fig.3.1). Up to August 1st 1993, 915 deep wells had been drilled, totalling 2,168,400 m, with 912 of these having been drilled either in western or central Yakutia (prospective area 1.35 million km²). As of October 1993, a total of 207,803 km of seismic data had been acquired, 125,985 km of which is CDP. 30 oil, gas and gas condensate fields have been discovered to date (Intera & *Sakhaneftegaz*, 1993; Thompson, 1994), nineteen in the Nepa-Botuobian region of south western Sakha and eleven in central Sakha (nine in the Vilyuyan region, one in the Subpotomian region and one in the Subverkhoyanian region). Fig.3.2 shows the location of these fields. Gas hydrates are known to exist but these remain little understood. The gas fields tend to be much deeper than the oil fields. On average, gas fields are at depths of 2 - 2½ km [4] whereas oil fields lie between 600 m and 1 km down. The Nepa-Botuobian and Vilyuyan regions contain 99.5% of the republic's oil and gas reserves and

[4] At 6519 m deep, the Srednevilyuyan field well no.27 is considered to be the deepest well in East Siberia and the Far East (Intera & Sakhaneftegaz, 1993). It was drilled in 1984 (*Arctic News Record*, 1985, p.19).

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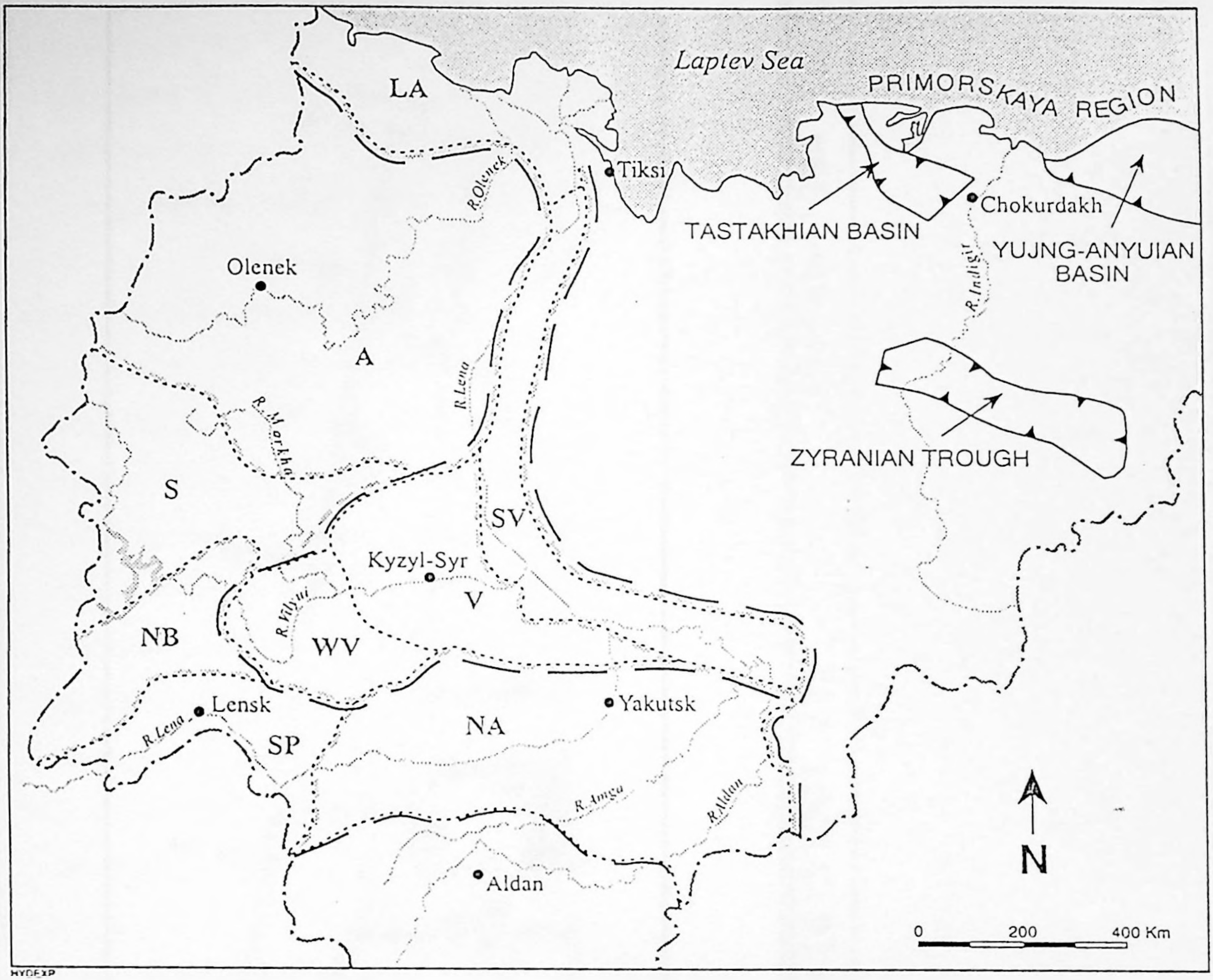
[illegible] At 6519 m deep, the Srednevilyuyskoe field well no.27 is considered to be the deepest well in East Siberia and the Far East (Sagers & Kryukov/Tagan, 1993). It was drilled in 1984 [illegible]

Figure 3.1 Oil and gas regions of the Sakha Republic. Source: Intera & *Sakhaneftegaz*, 1993.



LEGEND

—·—·—	REPUBLIC SAKHA (YAKUTIA) BORDER
— —	OIL/GAS PROVINCE BOUNDARY
....	OIL/GAS REGION BOUNDARY
	TECTONIC BOUNDARY
	LARGE SCALE TECTONIC BOUNDARY

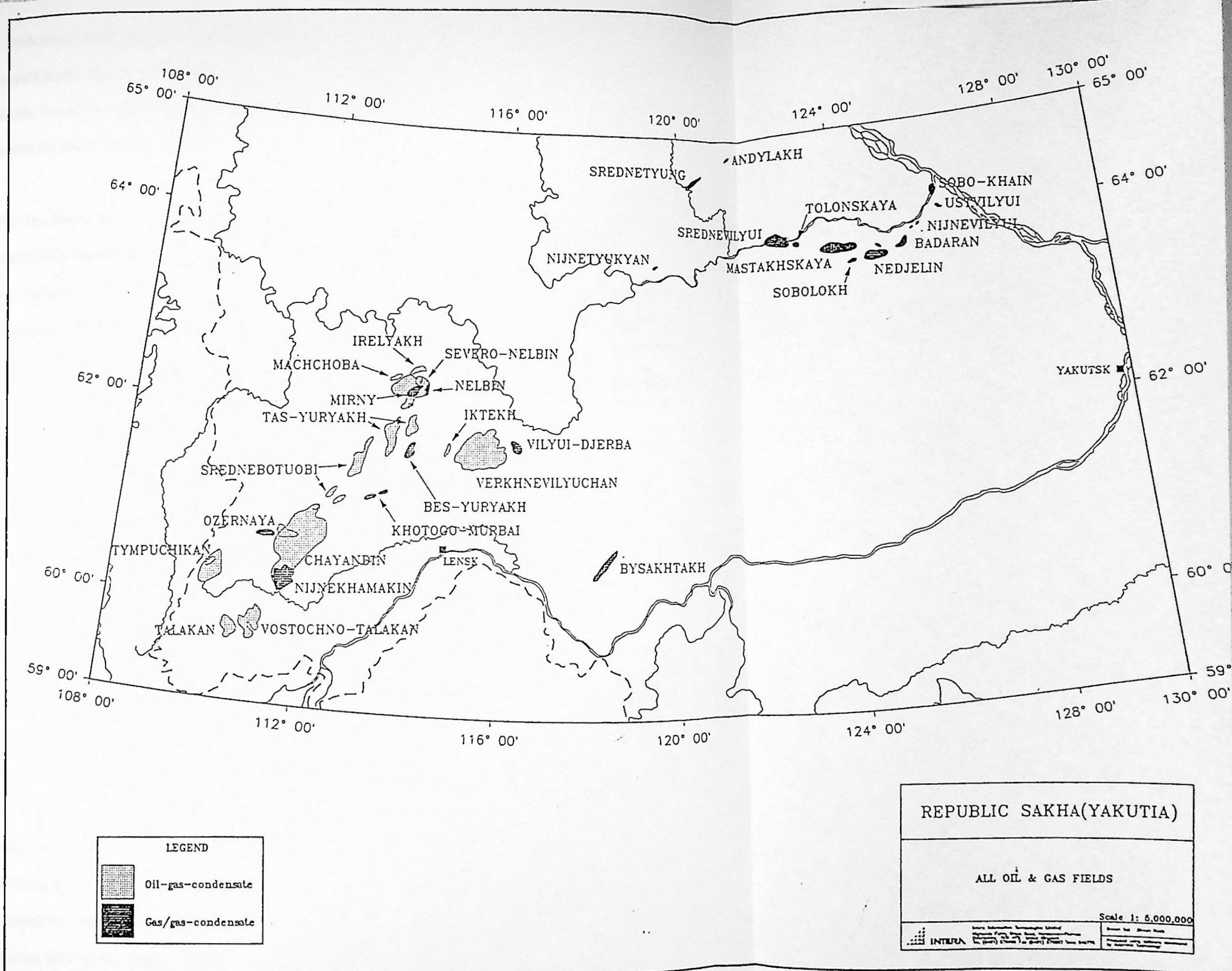
OIL & GAS REGIONS

NB	Nepa-Botuobian
SP	Sub Patomian
NA	North Aldanian
WV	West Vilyuian
S	Syugderian
A	Anabarian
V	Vilyuian
LA	Lena-Anabarian
SV	Sub Verkhoyanian

INTERA
YAKUTSKGEOFISIKA

Republic Sakha (Yakutia)
Hydrocarbon Exploration Regions

Figure 3.2 Oil and gas fields of the Sakha Republic. Source: Intera & *Sakhaneftegaz*, 1993.



have been surveyed in greater detail than all other parts of Sakha's vast oil and gas province. They are significantly different in geological terms. The two regions will be examined briefly below. Appendix 1 contains detailed statistical data, including data for individual gas fields, and therefore I have only included the most significant figures in the following two sections.

3.1.2.1 The Nepa-Botuobian Region.

Estimated recoverable reserves for the Nepa-Botuobian region are 789 BCM. The largest gas fields in the republic occur here; the Srednebotuobinskoye, the Taas-Yuryakhskoye and Verkhne-Vilyuychanskoye fields, where exploration and evaluation have apparently been completed, containing estimated reserves of 400 BCM. The geology of the region is Vendian and Cambrian (very old schist and gneiss). It is extremely rare to find such an old oil and gas bearing region, the only other country with pre-Cambrian oil and gas being Australia (Thompson, 1994). 42.8% of all deep drilling in the republic has occurred here, with well depths averaging 2000 m and a drilling density of 9.28 m/km^2. At present, gas from the Srednebotuobinskoye field fuels the diamond-mining centre of Mirnyy. The region's gas has commercial concentrations of helium (especially high), ethane, propane and butane (see Appendix 1 for more details).

3.1.2.2 The Vilyuyan Region.

Unlike the Nepa-Botuobian region, only gas and gas-condensate fields occur here. Estimated recoverable gas reserves for the Vilyuyan region are 506 BCM. In 1988 estimates gave a figure of 2.44 TCM, though this is now considered to be a gross over-estimation. *Sakhaneftegaz* specialists have confirmed that the region is just over half explored. The two main gas fields here are the Srednevilyuyskoye, with proven reserves of 166.7 BCM and the Srednetyungskoye, with reserves amounting to 165.74 BCM. The Sredetyungskoye is also one of the biggest gas-condensate fields in the republic, with gas containing roughly 55.6 g/m^3 of condensate. Combined, these reserves represent 65% of the region's reserve total. Proven reserves for the Sobolokh-Nedzhelinskoye field are only 33 BCM though it is believed that these could be raised to 150-200 BCM. The region is [illegible] surveyed in greater detail than all other parts of Russia's vast oil and gas provinces. They [illegible] only referred to geological works. The two regions will be examined briefly below [illegible] detailed statistical data, including data for individual gas fields, and therefore I [illegible] the most significant fields in the following sub-sections.

[illegible] The Volga-Urals [illegible] Region

[illegible] reserves [illegible] [illegible] [illegible] depths [illegible] [illegible] (see Appendix 1 for more details).

[illegible] The Vilyuisk Region

[illegible] the Volga-Urals region, only gas and gas-condensate fields occur here. [illegible] reserves for the Vilyuisk region are 500 BCM. In [illegible] estimates gave a figure of [illegible], though this is now considered to be a gross over-estimation. [illegible] that the region is just over half explored. The two main gas fields [illegible] and the [illegible], with proven reserves of 166.7 BCM and the [illegible], with reserves [illegible] BCM. The [illegible] is also one of the biggest gas-condensate fields [illegible], with gas containing roughly 35% share of condensate. Combined, these reserves [illegible] of the region's reserve total. Proven reserves for the [illegible] field [illegible] BCM though it is believed that these could be raised to [illegible] BCM. The region is characterized by predominantly Permian and Triassic geology; it has undergone 34.2% of total deep drilling, with the average well depth being 3500 m and a drilling density of 5.94 m/km². At present gas from the Tolon-Mastakhskoye and Srednevilyuyskoye fields is transmitted to Yakutsk and its environs. The Ust'-Vilyuyskoye field, the original source for the Taas-Tumus - Yakutsk - Bestyakh pipeline, has been depleted.

3.1.2.3 Other Regions: Lena-Anabarian, Anabarian, North Aldanian, Subverkhoyanian and Subpotomian.

The Anabarian, North Aldanian and Subverkhoyanian regions are regarded as the least investigated parts of Sakha's oil and gas province. The Subpotomian region has undergone slightly more geophysical surveying. Drilling densities in these regions vary from 1.25 to 0.07 m/km², the latter figure being for the least explored Anabarian region. According to Stephen Thompson (1994) of Intera Information Technologies[5] the Lena-Anabarian and Anabarian regions possess considerable potential for gas and particularly oil. The existence of hydrocarbons in this north western part of Sakha has been known since oil was discovered by American geophysicists in the former region in the 1940s. However, Wilson (1989, p.238) says that exploration for oil in the Lena-Anabarian region began in 1938 near Nordvik (on the border with Krasnoyarsk Kray) under the direction of the Geological Administration of *Glavsevmorput'*. He reports (1989, p.239) that exploratory work was underway in the late 1980s in the Nordvik area and that since 1980 exploratory work had also been taking place near Taymylyr on the east bank of the Olenyok River. The government is particularly hopeful that significant hydrocarbon discoveries will be made after extensive exploratory work in these regions. A priority usage of the hydrocarbons would be as a fuel source for the republic's newest and largest diamond placer deposit, Ebelyakh, which is situated on the east bank of the Anabar River. It went into operation in 1984 (Shabad, 1984, p.706). There is always the possibility of other diamond deposits being discovered in the same area since there has been a trend towards the

[5]Intera, a British company, is the official agent of Sakhaneftegaz.

development of more northerly mines and these would clearly benefit from a local fuel supply. The Olenyok tar sands of the Anabarian region are believed to contain up to half of the C.I.S.'s bitumen resources (Intera & *Sakhaneftegaz*, 1993). The largest bitumen concentrations lie along the Siligir River, 960 km north west of Yakutsk (Wilson, 1989, p.243). Wilson (1989, p.244) also reports that gas yields of 0.1 MCM per day were obtained near the Russkaya River in the eastern part of the North Aldanian region. He also claims there could be as much bitumen in this area as in the Anabarian region.

3.2 GAS TRANSPORT INFRASTRUCTURE

It would be fair to say that gas transport infrastructure in the republic is decidedly sparse, but this is understandable in view of the constraints and current state of gas production already discussed. One would therefore expect very little available information on this subject and to a great extent this is the case. However, a considerable amount has been written on the Taas-Tumus - Yakutsk - Bestyakh pipeline (and the Kysyl-Syr spur), shown in Fig.3.3, and this stems from the fact that it was the world's first gas pipeline built in a region of permafrost (Kenopasevich *et al*, 1969, p.40; Harris, 1986, p.176; Kondrat'yev, 1988, p.4). Accordingly, this pipeline will be examined in more depth than the others.

3.2.1 The Taas-Tumus - Yakutsk - Bestyakh gas pipeline (including the Kysyl-Syr spur).

This pipeline project, developed by the *Yuzhgiprogaz* Institute (located in Donetsk) and *VNIIST* (All-Union Scientific-Research Institute for Pipeline Construction), began in 1963 (Zubov, 1963). Construction was carried out in two stages, the first being the Taas-Tumus - Yakutsk section, as shown in Fig.3.4. Taas-Tumus, located near the mouth of the Vilyuy River, is where gas was first discovered in the republic, and it is interesting to note that even though the official title would suggest that this is where the pipeline begins, its actual departure point is Promyshlenniy, several kilometres to the north west. The pipeline reached Yakutsk in November 1967 having covered a development of more remotely sited and more recent major trunk lines a

Despite the needs of the Amderma region are fulfilled essentially up to half

reserves (Lenin & Sakhanyihovs, 1993). The largest ... concentrations

stone, 260 km north-west of Yakutsk (Wilson, 1989, p.143; Wilson (1983), p.

gas yields of 0.1 MCM per day were obtained near the Kuskhaya River in

North Athutian region. He also claims that ... of much

Amderma region.

3.2 GAS TRANSPORT INFRASTRUCTURE

It would be fair to say that gas ... comprehensive ... would therefore expect ... the area. However, a ... pipeline (and the Aquarelian spur) shown in Fig.3.3, and ... works from the ... models that gas pipeline built in a region of permafrost (Kornakovich et al., 1988, p.xxx; Kondratyev, 1988, p.6). Accordingly, this pipeline will be ... than the others.

3.2.1 The Taas-Tumus - Yakutsk - Pokrovsk gas pipeline (including the Ky

This pipeline project, developed by the Fundamental Institute (located in ... (now Yakutsk) Research Institute for Pipeline Construction), began in 196... Construction was carried out in two stages, the first being the Taas-Tumus ... shown in Fig.3.3. Taas-Tumus, located near the mouth of the Vilyuy River, ... discovered in the appendix, and it is interesting to note that, even though ... suggest that this is where the pipeline begins, its actual departure point is ... kilometres to the north-west. The pipeline reached Yakutsk in November 19

Figure 3.3 Schematic map of the Taas-Tumus - Yakutsk - Bestyakh gas pipeline, including the Kysyl-Syr spur. Source: Kirillin, 1974.

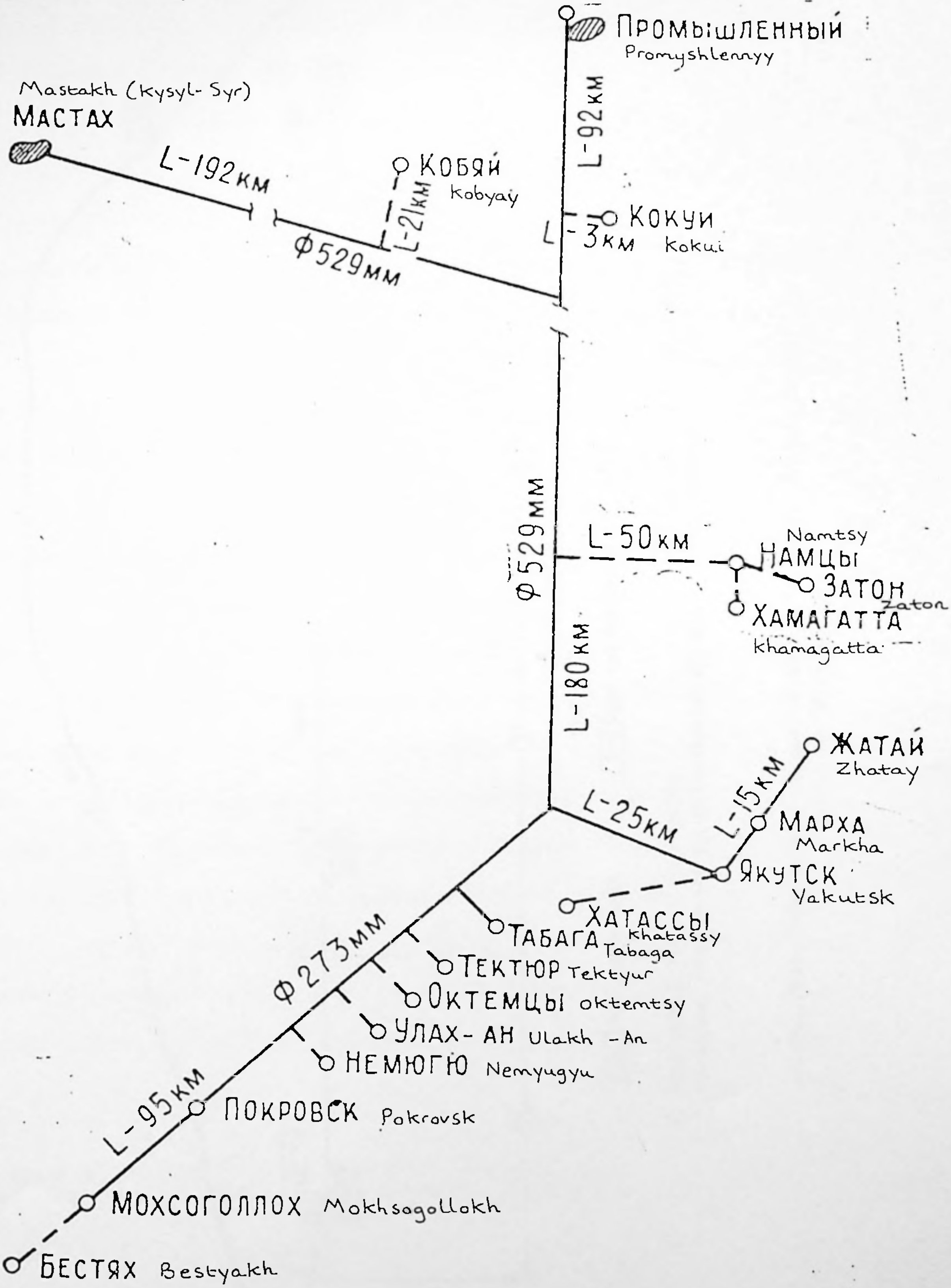
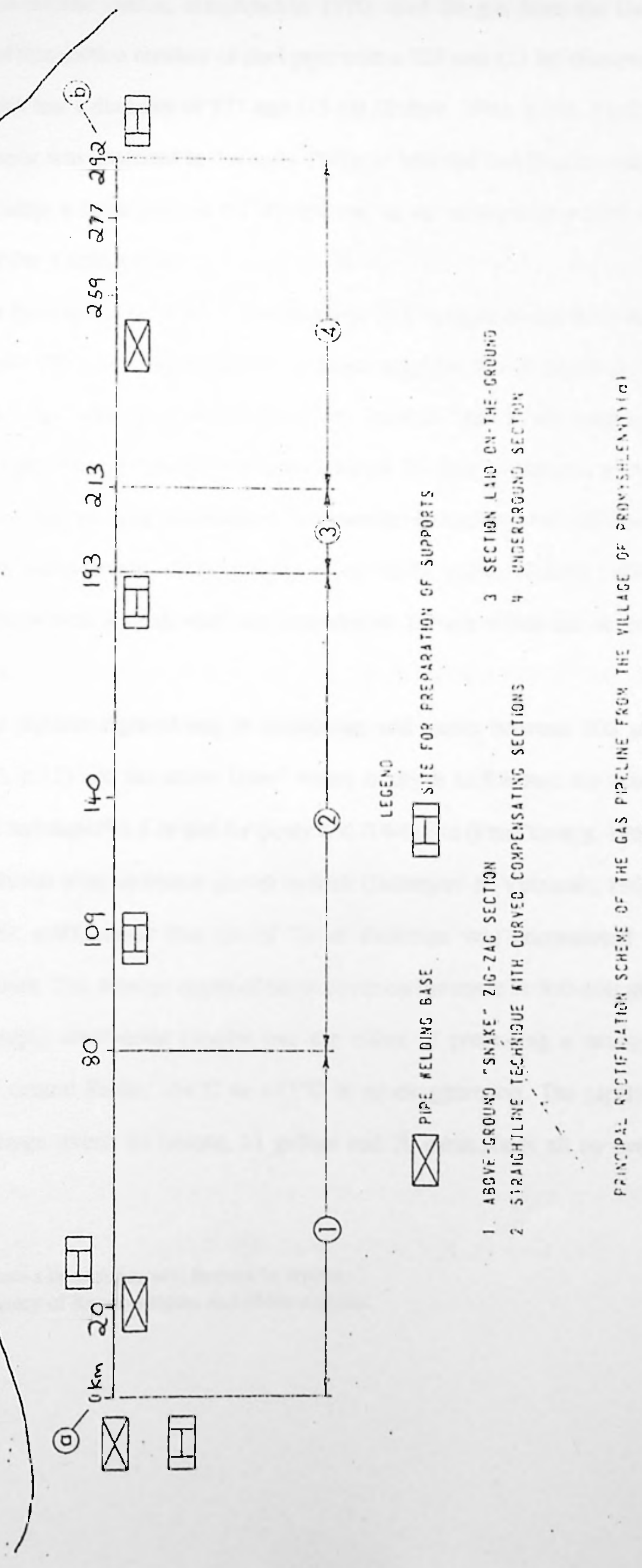


Figure 3.4 Schematic map of the Taas-Tumus - Yakutsk pipeline section. Source: Bukreyev & Vessarab, 1969.



distance of 310 km (Shabad, 1969, p.40) and it went into operation in December of the same year (Altunin *et al*, 1970, p.24). A gas-turbine station, completed in 1970, used the gas from the Ust'-Vilyuyskoye field. The majority of this section consists of steel pipe with a 529 mm (21 in) diameter, although the 25 km spur to Yakutsk has a diameter of 377 mm (15 in) (Zubov, 1963, p.10). Kirillin (1974, p.122) indicates that this spur was extended in the early 1970s to Markha and Zhatay, some 15 km north east of Yakutsk. Zhatay, a large port on the River Lena, is the storage centre for all imported oil products destined for the Yakutsk area.

The second section is that from kilometre 274[6] to the Pokrovsk, Mokhsogollok and Bestyakh conurbation, where a cement mill (200,000 ton capacity), a large panelling-block business, a reinforced-concrete factory and a large vehicle-repair workshop are located. This is the centre of Sakha's construction industry. The pipeline on this spur has a diameter of 273 mm (11 in) and a total distance of 95 km. *Pravda* reported that the spur had reached Bestyakh in November 1968 (Shabad, 1969, p.40) and the pipeline was completed in 1969 (Altunin *et al*, 1970, p.24). Kirillin (1974, p.122) also indicates that soon afterwards, a small spur was extended to Tabaga which lies several kilometres to the south of Yakutsk.

The permafrost along the pipeline right-of-way is continuous and varies between 200 and 300 m in depth (Shchepkin, 1970, p.31) and the active layer[7] varies in depth as follows: for sands not more than 2.5 m, for *suglinok* and *supes*[8] 1.5 m and for peaty soil 0.6-0.8 m (Perel'tsvayg, 1964, p.6). The lithology is basically alluvial with no coarse gravel or rock (Bukreyev & Vessarab, 1969, p.76). Kenopasevich *et al.* (1969, p.40) report that ice of 7+ m thickness was encountered at relatively shallow depths on the route. The average depth of snow cover on the route is 300-400 mm (Zubov, 1963, p.10) and the sharply continental climate has the effect of producing a massive temperature range in this part of central Sakha: -64°C to +37°C is no exaggeration. The pipeline crosses spring-flooded areas, 17 large rivers, 20 brooks, 11 gullies and 70 earth roads all by over-

[6] 274 km from Taas-Tumus.
[7] The layer nearest the surface that thaws in summer and freezes in winter.
[8] These terms are defined in the Glossary of Russian terms and abbreviations.

passes (Zubov, 1963, p.11) and in some cases transit spans of 50-75 m were needed (Shchepkin, 1970, p.31). Quite clearly, such conditions provided a vast array of technical problems in a time when very little was known about construction in cold regions, let alone that involving gas transmission systems.

Construction, conducted by the 8th Construction-Installation Administration of the All-Union Trust for Oil Pipeline Installation (*Trest Nefteprovodmontazh*), took the following form. Between Taas-Tumus and Yakutsk the pipeline was built partly overground (193 km), on the ground (20 km) and underground (97 km) (Bukreyev & Vessarab, 1969, p.73). Construction was performed by two spreads working from opposite ends of the pipeline in shifts. Each spread consisted of a number of pipe-layer operators, bulldozer operators, welders, pipe cutters, diesel mechanics and carpenters. Two construction techniques, shown in Fig.3.5, were used for the above-ground section: the zig-zag, so-called "snake" type (0-80th km), and the straight-line technique, which included slightly curved compensating sections (80th to 193rd km). These techniques were used to allow for thermal expansion and contraction. The project was entirely experimental and this was particularly the case for the two construction techniques mentioned above. They had never been used before and the journal *Stroitel'stvo truboprovodov* (Pipeline Construction) featured many articles regarding the project during the 1960s and early 1970s, specifically to report on these pioneering pipeline construction methods. As Terence Armstrong (1968, p.185) discovered during a trip to former-Yakutia in 1967, the expected amount of deformation as a result of disturbance of permafrost (the pipeline had no thermal insulation) was unknown and the Permafrost Institute in Yakutsk was researching this matter in depth. The project provided experiences that were to prove invaluable for many future northern pipeline construction projects, especially the Messoyakha - Noril'sk gas pipeline (Spiridonov & Gekhman, 1969, p.98). Completed in 1969, this was the first gas pipeline built inside the Arctic Circle (Kondrat'yev, 1988, p.4).

The rate of construction was determined by the drilling of holes for pile supports and 8000 m of these were drilled in all using PPU-3 and PPU-3M steam needle rigs. A wide variety of pumps (Zubov, 1963, p.11) and in some cases transit spans of 50-75 m were needed [illegible] 1970, p.31). Quite clearly, such conditions provided a vast array of technical problems [illegible] when very little was known about construction in cold regions, let alone that of [illegible] transmission systems.

Construction, conducted by the Jan. Construction Installation Administration [illegible] Union Trust for Oil Pipeline Installation [illegible] Between Tass-Tumus and Yakutsk the pipeline was [illegible] (20 km) and underground (57 km) (Baldayev et al. [illegible] by two spreads working from [illegible] number of pipe-layer operators, welders, [illegible] carpenters. Two construction techniques were [illegible] the zig-zag, so-called 'snake' type of [illegible] slightly curved compensating sections [illegible] thermal expansion and contraction. The project was [illegible] the case for the two construction techniques mentioned above. They had never been [illegible] the journal *Stroitel'stvo truboprovodov* (Pipeline Construction) featured many articles [illegible] project during the 1960s and early 1970s, specifically to report on these pioneer[illegible] construction methods. As Terence Armstrong (1998, p.185) discovered during a [illegible] Yakutia in 1967, the expected amount of deformation as a result of disturbance of [illegible] pipeline had no thermal insulation) was excessive and the Permafrost Institute [illegible] researching this matter in depth. The project provided experiences that were to prove [illegible] many future northern pipeline construction projects, especially the Messoyakha [illegible] pipeline (Spiridonov in Gedman, 1990, p.98). Completed in 1969, this was the fi[illegible] built inside the Arctic Circle (Kondrashev, 1988, p.4).

The rate of construction was determined by the drilling of holes for pile sup[illegible] m of these were drilled in all using PPU-3 and PPU-3M steam needle rigs. A

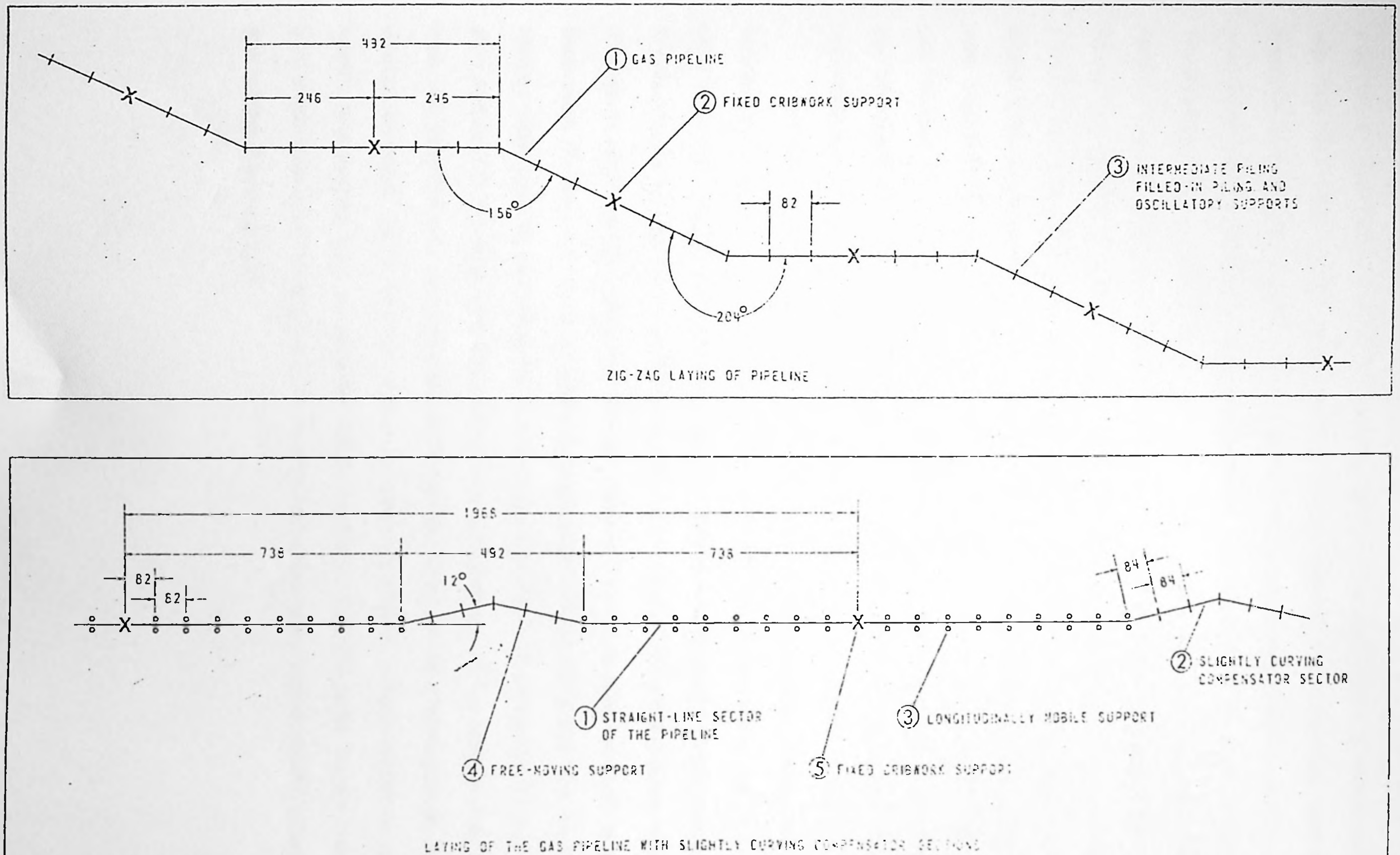


Figure 3.5 Diagram showing the two different construction techniques used on the above-ground section of the Taas-Tumus - Yakutsk pipeline. Source: Bukreyev & Vessarab, 1969.

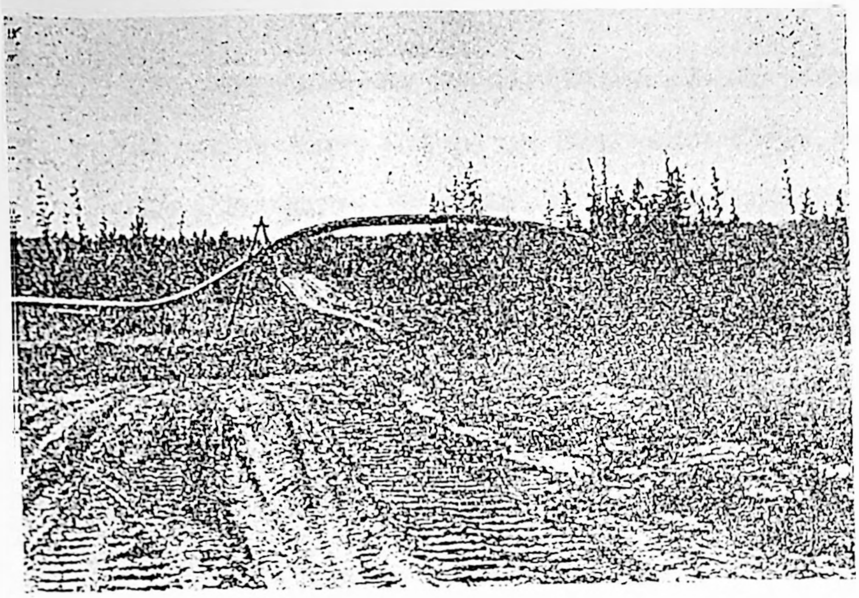
ALL MEASUREMENTS ARE IN FEET

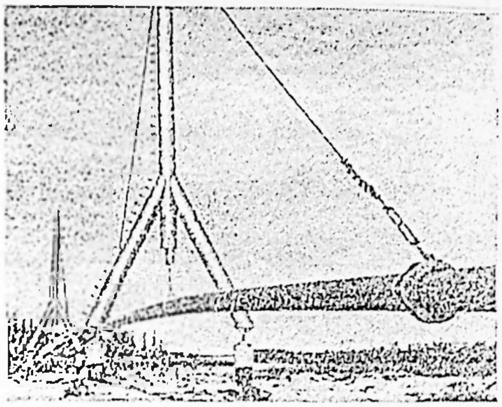
supports were used, as shown in Fig.3.6. In marshes, fixed crib and pile supports; in swamps, piles with back-filled supports; for zig-zag sections, hinged supports; for straight-line sections, longitudinally mobile supports; for curved compensating sections, free moving supports. All of these were manufactured with wooden (larch) components at four points along the route, including Promyshlenniy. The supports were dug into the permafrost below the active layer, the depth estimated to be such that the frost adhesion of permafrost ground to the base of the support would be stronger than the adhesion in the active layer (Shebsman, 1963, p.6). Bukreyev and Vessarab (1969, p.73) say that significant problems were encountered on zig-zag sections as a result of the different heights of the hinged and fixed-crib supports and the different lengths of the pipeline suspension arms. Such problems were not experienced on the straight-line section, where the height from the pipe bottom to the surface was constant. Few problems were experienced during the underground pipe-laying operations (Kenopasevich *et al*, 1969, p.40) and this was attributed to more favourable soil conditions in the southern section. The pipeline was buried at an average depth of 0.75 m.

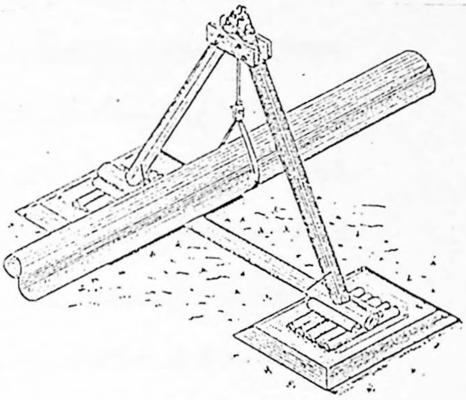
Vehicles used on the route included GTT, ATL-5 and GAZ-47 all-terrain vehicles used for carrying pipe, supports and other materials, T100 and T100B tractors in summer, and ZIL-157 automobiles. MI-6, MI-2 and B-2 helicopters and AN-2 aircraft were also used for larger payloads. Machinery and equipment movements on the majority of the right-of-way occurred during winter (October to April), as did welding and clearing operations. Special attention was paid to the conservation of moss cover during the construction operations. Brushwood "paving" was used to reinforce winter roads on small rivers and on large rivers multiple brushwood layers were used to allow additional ice formation. UGT-7 rigs were used for pipe bending at 20 km intervals along the route, with MP-200 heaters used to heat the pipes beforehand. Some machinery movements, pipeline cleaning and grease coating operations took place during the summer. Wooden bridges on crib supports were built for truck and all-terrain vehicle operations during this period. Leonov (1965, p.18) revealed that construction of part of the underground section during summer resulted in large-scale melting of frozen ground.

supports were used, as shown in Fig. 1.8. In summer, fixed crib and pile supports in sections with back-filled supports; for zig-zag sections, hinged supports; for straight-line sections, longitudinally mobile supports; for curved compensating sections, free-moving supports. All of these were manufactured with wooden (larch) components at base points along the route, including Pionyorskiy. The supports were dug into the permafrost below the active layer, the depth estimated to be such that the frost adhesion of permafrost to the piles of the supports would be stronger than the adhesion in the active layer. [illegible] (1992, p.17) say that significant problems [illegible] heights of the hinged and fixed [illegible] were [illegible] active. Such problems were [illegible] pipe bottom to the surface [illegible] pipe-laying operations [illegible] with conditions in the [illegible]. The pipeline was buried at an average depth of 0.75 m.

Vehicles used on the route included GTT, ATT-5 and DM-[illegible] all-terrain vehicles used for carrying pipe, supports and other materials, T100 and T130 tractors in summer, and ZIL-157 automobiles. Mi-6, Mi-2 and B-8 helicopters and AN-2 aircraft were also used for larger payloads. Machinery and equipment movements on the majority of the right-of-way occurred during winter (October to April), as did welding and clearing operations. Special attention was paid to the conservation of moss cover during the construction operations. Brushwood "paving" was used to reinforce winter roads on small rivers and on large rivers multiple brushwood layers were used to allow additional ice formation. MGT-7 rigs were used for pipe bending at 20 km intervals along the route, with MP-200 heaters used to heat the pipes beforehand. Some machinery movements, pipeline repairing and grease coating operations took place during the summer. Wooden bridges on crib supports were built for truck and all-terrain vehicle operations during this period. Lukanov (1995, p.15) revealed that construction of part of the underground section during summer resulted in large-scale melting of frozen ground.



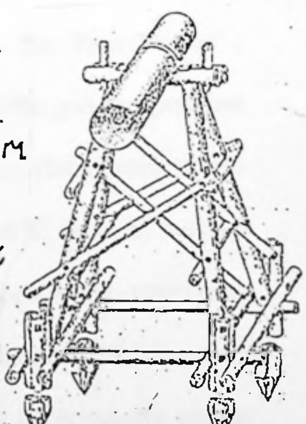




Above: Raised section on wooden cradle support. Note the vehicle tracks in the foreground. (Kirillin, 1974.)

Top: River crossing on wooden cradle supports. (Shchepkin, 1970.)
Above: Cradle support with suspension bracket. (Perel'tsvayg, 1964.)

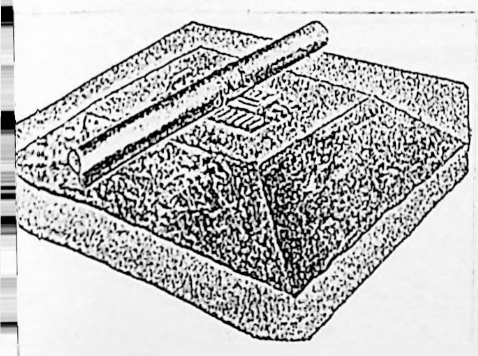
Figure 3.6 Pipeline supports. A wide variety of simple wooden supports were used on the above-ground and ground level sections of the Taas-Tumus - Yakutsk pipeline.

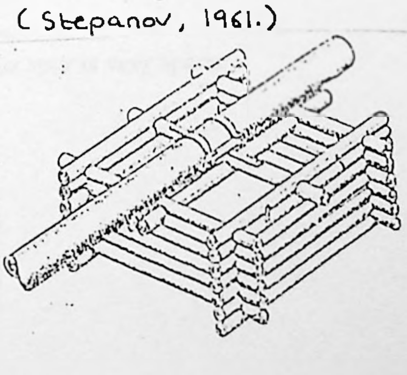


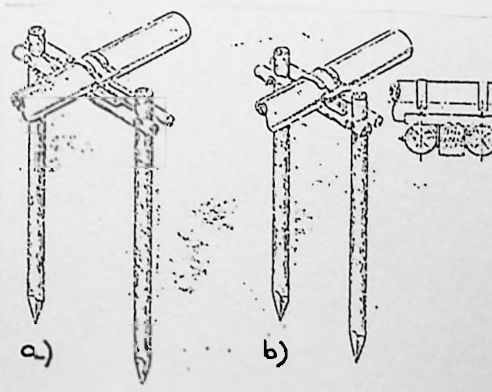
Right: Fixed support on wooden piles. (Stepanov, A.M 1961. Stroitel'stvo truboprovodov, Vol. 6, No. 6, p. 2-6.)

Below: Ground level sliding support. (Stepanov, A.M. 1961. Stroitel'stvo truboprovodov, Vol. 6, No. 6, p. 2-6.)

Below: Fixed crib support. (Stepanov, 1961.)
Below right: Wooden pile supports. a) sliding b) fixed. (Stepanov, 1961.)







Since the pipeline went into operation, a number of spurs have been added to allow smaller settlements to benefit from the gas. These include Kobyai, Namtsy, Zaton, Khamagatta, Magan, Tabaya, Tektyur, Oktemtsy, Ulakh-An, and Nemyugyu. The first 92 km of the pipeline (Taas-Tumus - connection point with Kysyl-Syr pipeline) is now obsolete, chiefly because the Ust'-Vilyuyskoye gas field has been depleted. From this field, the pipeline was transmitting no more than 184 MCM per annum (this being the peak output for 1970) (Shabad & Mote, 1977, p.44), with Yakutsk receiving 200,000 to 250,000 CM per day (Shabad, 1973, p.478).

Central Sakha now depends upon the gas supplied from the Srednevilyuyskoye and Tolon-Mastakhskoye fields via the 192 km (529 mm / 21 in diameter) Kysyl-Syr spur[9] (see Fig.3.3), which was laid in 1973 (Shabad & Mote, 1977, p.44). The overall length of pipeline between these fields and Yakutsk is approximately 400 km. Permafrost reaches a depth of 350 m along the spur route and the average depth of snow is 25-30 cm (Kamensky *et al.*, 1993, p.322). Soon after the opening of this spur, Yakutsk was receiving 1 MCM per day (435 MCM total for 1974) and in the mid-1980s, 95% of Sakha's gas production was coming from Tolon-Mastakhskoye (Wilson, 1989, p.240). A 21 km spur runs from this pipeline to Kobyay (south west of Taas-Tumus). Kamensky *et al.* (1993, p.322) and Petroconsultants (1993) report that there are currently two strings running from Kysyl-Syr to Yakutsk. A third is under construction. The following figures represent the modern-day operating regime characteristics of the pipeline (i.e. excluding the Taas-Tumus - kilometre 92 section) as outlined in Kamensky *et al.* (1993). At the head (inlet) the gas temperature ranges from -14°C to -20°C and the pressure is 5.5 MPa (781 psi) and at the gas distribution centre in Yakutsk (outlet) the figures are +0.5°C to +2.5°C (summer) or -6.7°C to -7.6°C (winter) and 2.5 MPa (355 psi) respectively. There are currently 9 gas-engine compressor stations on the two-string route, whereas originally the gas was free flowing (Zubov, 1963, p.). The planned 1991 capacity for the two strings was 1.4 BCM (Petroconsultants, 1993). Little is known of accidents on the pipelines, but one was reported on 20th November 1987 in the Soviet Press (*ESPSNA*, 1987, p.35;

[9]Construction information for this spur is very sparse.

Since the pipeline went into operation, a number of spurs have been added to
settlements to benefit from the gas. These include [illegible], [illegible], [illegible]
Takhta, [illegible], [illegible], Ufala-Ak, and [illegible]. The first [illegible] of the pi[illegible]
Tanap - connection point with [illegible] pipeline system, operation, already [illegible]
[illegible] gas field has been depleted. From [illegible], total annual pipeline [illegible]
134 MCM per annum (this being the peak [illegible]) ([illegible] et al., 199[illegible]
[illegible] receiving [illegible] pipeline [illegible], p. 285).

Central Russia now depends on [illegible] and gas supplied from the [illegible]
Medvezhye fields via the [illegible] pipeline [illegible] spur [illegible]
was laid in 1971 ([illegible]). The overall length of pipeline between [illegible]
and Vuktyl is approximately [illegible] a depth of [illegible]
and the average depth of snow [illegible] (Kuznetsov et al., 1992, p.322) [illegible]
of this spur, 1 MCM was [illegible] 2413 MCM [illegible] for 1996 [illegible]
1990s, 95% of [illegible] gas production was coming from [illegible]
p.265. A 23 km spur runs from the pipeline to [illegible] (south-east of [illegible]
al. (1992, p.322) and [illegible] (1993) report that there are currently two [illegible]
from [illegible] to Vuktyl. A third is under construction. The following figures [illegible]
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[illegible] 92 section) as outlined in Kuznetsov et al. (1992). At the head (inlet) [illegible]
ranges from -14°C to -20°C and the pressure is 5.4 MPa (783 psi) and at the gas [illegible]
in Vuktyl (outlet) the figures are +0.5°C to +2.5°C (summer) or -6.7°C to -7.0°C [illegible]
MPa (255 psi) respectively. There are currently 9 gas-engine compressor stations on [illegible]
route, whereas originally the gas was free flowing (Zubov, 1983, p. [illegible]). The planned [illegible]
for the two storage was 1.6 MCM ([illegible], 1993). Little is known of [illegible]
pipelines, but one was reported on 30th November 1987 in the [illegible] River [illegible]

[illegible] Construction information for this spur is very sparse.

Izvestiya, 1987, p.6). An explosion in a pipeline forced the Yakutsk power plant to be switched over to reserve oil.

Very little has been written on the interactions between these pipelines and the permafrost. However, a paper presented at the Sixth International Permafrost Conference[10] (Kamensky *et al.*, 1993) did address this matter and thus provides us with an almost unique insight into the operational problems of gas pipelines in *the* classic permafrost region and its most continental of all continental climates. One earlier paper (Turbina, 1980) examined environmental changes along a 60 km stretch of the original pipeline, lying 30 km northwest of Yakutsk. Although Altunin *et al.* (1970, p.25) reported that no "expulsion" of the initial pipeline (buried section) from the ground had been observed during the first year or so of operation, both Kamensky *et al.* and Turbina reveal displacements of this and the subsequent pipeline as a result of a variety of periglacial processes. N.A.Grave (1984, p.118), drawing from information in Turbina's paper, does suggest that disturbances in the buried section are relatively minor. Pipeline displacements are to be considered in depth in chapter 5.

3.2.2 Other pipelines in the republic.

The only other operational pipeline in the republic is the 171 km (600 mm / 24 in) Taas-Yuryakh (on the Srednebotuobinskoye gas field) - Mirnyy gas pipeline, which was completed in June 1987 (Wilson, 1989, p.248; ZumBrunnen, 1990, p.93; Intera & *Sakhaneftegaz*, 1993). The pipeline supplies the diamond-mining centre with gas from the Srednebotuobinskoye and Severo-Nelbinskoye fields (Intera & *Sakhaneftegaz*, 1993). For some of the way it runs parallel to the Lensk - Mirnyy all-weather highway. Wilson also mentions a short gas pipeline between Irelyakha and Mirnyy, which was supposedly completed after the Irelyakhskoye field was discovered in 1981. However, there is no mention of this in the 1993 Intera & *Sakhaneftegaz* report. Likewise, the report does not

[10]Held in Beijing, China, July 5-9, 1993.

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3.2.3 Other pipelines in the republic.

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[10]Held in Beijing, China, July 5-9, 1993.

confirm Wilson's revelation that the Taas-Yuryakh - Mirnyy pipeline was being extended 65 km to Svetlyy on the Vilyuy River, where the Vilyuy-3 hydro-electric station is still under construction[11].

It is reported that a gas pipeline is under construction from Mirnyy to the diamond mining centres of Udachnyy and Aykhal, which lie approximately 400 km to the north (Intera & *Sakhaneftegaz*, 1993). Unfortunately, there are no further details concerning this project.

3.3 FOREIGN INTEREST IN AND INVOLVEMENT WITH THE DEVELOPMENT OF SAKHA'S NATURAL GAS

3.3.1 Past interest.

The only project from the past was the ill-fated Yakutia Gas Project, proposals for which date back to the late 1960s. The project started out as a bilateral effort between the Soviets and the Japanese, but the Americans came on stage in 1972. A trilateral agreement was signed in November 1974 between the Russians, a consortium of Japanese companies headed by Tokyo Gas, the El Paso LNG Company and Occidental Petroleum Corporation, commercial banks and Export-Import banks (Egyed, 1983, p.71; Stern, 1983, p.375). The proposal involved gas production from fields in the Nepa-Botuobian and Vilyuyan regions amounting to 30 BCM per annum, approximately half of which would go to the Russians and power a pipeline to the Pacific coast, and the other half would be split between the Japanese and the Americans (Lister, 1979a, p.621). In return Japan and the USA would provide technology, equipment and credits for the two year exploration phase that would be needed to prove the existence of at least 1 TCM of gas. A second phase would involve the construction of a 3000 km (1420 mm / 56 inch) pipeline to Ol'ga in Primor'ye Kray on the Pacific coast (see Fig.3.7). Originally, the pipeline was to head due east terminating in Magadan, but for a number of reasons the proposal was dropped[12]. This issue will be discussed further in the following

---

[11]The station and dam should have been completed in 1990. A great deal of work remains however and it is impossible even today to cite possible completion dates (Shats, 1993).
[12]The Japanese had in fact been eager to use this route (Mote, 1983b, p.153).

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Svetlyy on the Vilyuy River, where the Vilyuy-3 hydroelectric station is with un

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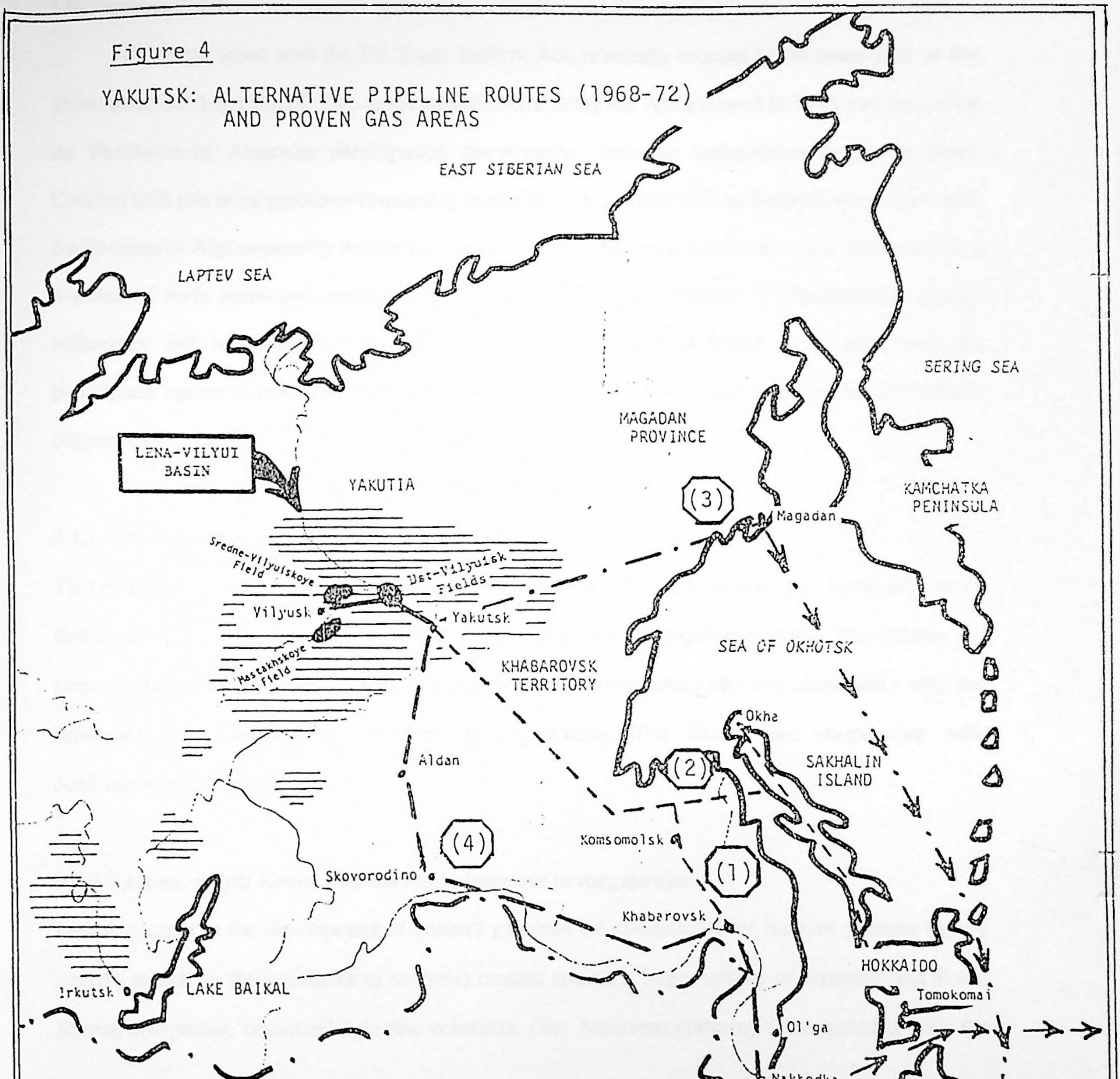
[12] In 1980 it had in fact been made so that ... (Sagers, 1993b, p.124).

Figure 3.7 Alternatives routes considered for the Yakutia Gas Project. Source: Egyed, 1983.



chapter. The final phase would have involved the construction of liquefaction facilities at Ol'ga and LNG tankers to deliver the gas to California and Japan.

Problems arose with the US Trade Reform Act, ironically enacted in the same year as the above-mentioned agreement. Two amendments[13] reinforcing the Act followed in 1975 and thus, with the likelihood of American participation deteriorating, Japanese commitment began to wane. Coupled with this were problems concerning exploration in Yakutia and the project's death knell was the invasion of Afghanistan by the Soviet Union in 1979, which was followed by the introduction of a series of trade restriction measures, including a ban on the transfer of advanced US energy technology and equipment to the USSR. Thereafter, the project made no progress and the participants agreed to postpone indefinitely a joint meeting that would have taken place in July 1980 (Egyed, 1983, p.88)[14].

3.3.2 Contemporary interest.

Two Pacific Rim nations dominate foreign interests in the republic's natural gas; Japan and South Korea have put forward proposals for large-scale production and pipeline projects. The Chinese are keen to join the Japanese and South Koreans, while the Americans (who are cooperating with the Japanese) and Austrians are involved in exploration. The British are cooperating with *Sakhaneftegaz*.

3.3.2.1 Japan, South Korea and the USA: interests in megaprojects.

Present interest in the development of Sakha's gas (and the construction of massive pipeline supply systems to deliver the gas direct to markets) centres around a large number of Japanese and South Korean companies, organized into two consortia. One American company is cooperating with the

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[13]The Jackson-Vanik and Stevenson amendments.

[14]Detailed information on this project can be found in: Lister, 1979a; Lister 1979b; Egyed, 1983; Stern 1983.

depot. The final phase would have involved the construction of liquefied na…
LNG tankers to deliver the gas to California and Japan.

Problems arose with the US Trade Reform Act, especially concer… above-mentioned agreements. Two amendments[13] restricting the Act which … the likelihood of American participation diminishing. Japanese … coupled with the more problems concerning exploration in Yakutia and th… the invasion of Afghanistan by the Soviet Union in 1979 which was follow… a series of trade restriction measures, including a ban on the transfer… technology and equipment to the USSR. Therefore the project participants agreed to postpone investments in the development of the Yakutia … (Lopez, 1985, p.88)[14].

3.3.3 Contemporary interest

The Pacific Rim nations' interest in foreign investment in the … Korea have put forward proposals for large-scale production and pipelin… hen to join the Japanese and South Koreans, while the Americans (w… Japanese) and American are interested in exploration. The … Vladivostok/Yuzhno-Sakhalinsk.

3.3.3.1 Japan, South Korea and the USA: Interest in development of the … Korean interest in the development of Yakutia gas (and the economic … systems to deliver the gas direct to mainland Korea) around a large … Korean companies, organised into two consortia. One American compa…

[13] The Jackson-Vanik and Stevenson amendments.
[14] Detailed information on this project can be found in L… 1985; Lopez, 1985.

Japanese. A small number of companies are presently involved in exploration for oil and gas in the republic.

The development of the gas is part of a wider project involving fields in both Sakha and Sakhalin Island which lies off the Khabarovsk Kray coast. According to Keun-Wook Paik (1993, p.300) if the "Vostok Plan" progresses as planned[15], 810 BCM per annum of gas would be supplied to Russia, 306.1 BCM per annum to South Korea and Japan, and 66.3 BCM per annum to North Korea by 2005. The plan envisaged the construction a 3050 km gas pipeline from Sakha to Khabarovsk by 2000, alongside the AYAM and BAM railways, as shown in Fig.3.8. This pipeline would join (at Khabarovsk) another pipeline connecting Sakhalin to North and South Korea and Fukuoka (Japan) which would have been completed by 1995. Clearly, such a timetable is wholly unrealistic and Paik does acknowledge the uncertainties involved.

Figure 3.8 Schematic map showing the route for the gas pipeline from the Sakha Republic to South Korea and Japan as envisaged in the Vostok Plan. It links up with the Sakhalin Island gas pipeline at Khabarovsk. Source: Paik, 1993.

[15]The Vostok Plan, devised by Nikolai Ryzhkov (former chairman of the USSR Council of Ministers), is a 20-year Russian Far East development campaign, focusing in particular on oil and gas resources.

Japan). A small number of companies are pursuing [illegible] for [illegible] gas [illegible] supplies.

The development of the gas is part of a wider project [illegible] in south Sakha and Sakhalin Island which lies off the Khabarovsk Kray coast. According to [illegible] (1993, p.200) if the "Vostok Plan" programme is [illegible], [illegible] a [illegible] BCM per annum to South Korea and Japan, [illegible] by 2005. This plan envisages [illegible] Khabarovsk by 2000, [illegible] would join (at Khabarovsk) [illegible] Sakhalin (Japan) [illegible] operators and Park [illegible]

Figure 3.5 Schematic map showing the route for the gas pipeline from the Sakha Republic to South Korea and Japan as envisaged in the Vostok Plan. It links up with the Sakhalin Island gas pipeline at Khabarovsk. Source: Paik, 1993.

[1]The Vostok Plan, devised by Nikolai Ryzhkov (former chairman of the USSR Council of Ministers), is a Soviet Russian Far East development campaign, focusing in particular on oil and gas resources.

It appears that the first step towards the realization of the Sakha portion of the project was taken in December 1991 when the Sakha government, Tokyo Boeki Development Ltd. (Japan) and Far East Energy Inc. (USA) signed a contract to carry out a feasibility study ($30 million), then to drill and finally to construct the gas pipeline at a total cost of $10-14 billion (Bagramyan, 1992, p.9; *Pipeline & Gas Journal*, 1992, p.2). This project actually represents a revival of the negotiations surrounding the aborted Yakutia Gas Project (RA Report, 1993a, p.106). Not surprisingly, T.Ue, managing director of TBD Ltd., pointed out:

"It is a very big project, so we are inviting companies from the US, Japan and other countries to participate." (Bagramyan, 1992, p.9).

Indeed, by the end of 1992, 12 other Japanese companies had expressed interest in the project (RA Report, 1993a, p.106). These include Japan National Oil Corp., Tokyo Gas Co., Tokyo Electric Power Co., Nippon Steel Corp. and JGC Corp. (Leaver, 1993a, p.74). Nigel Leaver (1992, p.68) reports that the feasibility study will now investigate the construction of two gas pipelines direct to Japan, via the Korean Peninsula. The aim is to produce 1.2 BCM per day by 2004 (*Oil & Gas Russia, Central Asia & the Caucasus*, 1994, p.44).

After a visit by Boris Yeltsin to Seoul in September 1992, an agreement was signed between Russia, the Sakha Republic and South Korea which laid the foundations for a feasibility study for gas exploration in Sakha and the construction of a gas pipeline to South Korea (Leaver, 1992, p.63 and 1993a, p.74; Manezhev, 1993, p.50; *Moscow News*, 1993, p.6). The Koreans formed a nine-member consortium led by the Korea Petroleum Development Corp. (PEDCO) which includes Daewoo Corp., Pohong Iron & Steel Co., Yukong Ltd., Samsung Co., Hyundai, Sangyong, Kohap and Lucky Goldstar International Corp. It will conduct the study with a Russian / Sakha consortium in a 50-50 JV. Since its formation, two more companies, Samwhan Corp. and Hanbo Energy Corp., have joined the consortium (Leaver, 1993b, p.45) and the study is expected to cost $80 million and a pre-feasibility study will cost in the region of $8.3 million. Korean experts say the cost of the entire project could be $20 billion (RA Report, 1993b, p.104). It is expected that the Far East Energy Inc. / TBD Ltd. group will merge with this consortium.

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"*It is a very big project, so we are inviting companies from* [illegible] *countries to participate.*" (Bagramyan, 1992, p.48).

Indeed, by the end of 1993, 12 other Japanese companies [illegible] project (JIA Report, 1993a, p.104). These include [illegible] Electric Power Co., Nippon Steel Corp. and [illegible] p.45) reports that the feasibility study will now investigate the construction of [illegible] direct to Japan, via the Korean Peninsula. The aim is to produce 32 bcm of gas per day by [illegible] the Russia, Central Asia & the Caucasus, 1994, p.44).

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The consortium put out a tender for the pre-feasibility study and in April 1994 it was almost certain that this would go to Intera Information Technologies (Thompson, 1994). Intera plans to find out by how much the Russians have over- or under-estimated the reserves status for Sakha's 30 oil and gas fields. The company will also estimate how much the main feasibility study will cost and how long this will take. The same estimates will be made for the proposed pipeline phase. This tender followed the shelving of an earlier pre-feasibility study. Political unrest was responsible for the cancellation of the second tripartite meeting (which had been scheduled for late March 1993) (RA Report, 1993b, p.104). The efforts of Intera will prove crucial to the future of foreign involvement in hydrocarbon development and pipeline construction since such massive projects will probably not be justified without proven reserves of 20 TCM.

It must also be borne in mind that problems will undoubtedly dog progress in JV development of Sakha's hydrocarbons. Stephen Thompson (1994) stresses that the Sakha projects and studies will move along very slowly indeed. This can be attributed to Russian and Yakut bureaucracy and incompetence as well as the aforementioned factors. For example, in spite of an agreement made in December 1992, Sakha failed to hand over field survey data to the Koreans. Foreigners will be less inclined to invest in the immediate future since the Sakha Republic is currently revising its foreign investment laws and laws on oil and gas. Thus, it is uncertain what the future holds for would-be investors. The national government is:

"....trying to create a legislative basis and national regime which will create good conditions for the fast attraction and effective operation of foreign investment." (Intera & *Sakhaneftegaz*, 1993).

A series of tax privileges are stipulated under the existing legislation and in order to provide stability for the investors and their property, one clause in the existing Law on Foreign Investments states that:

"....should new legislation make the conditions of a foreign investors activity worse, then for the following ten years acts being in force in the Republic at the moment of the investor's registration are to be used." (Intera & Sakhaneftegaz, 1993).

Thompson labels the Sakha Republic a "next century place". It is not hard to see why.

The consortium put out a tender for the pre-feasibility study and it [illegible] certain that this would go to Intera Information Technologies (Thompson, [illegible] est by how much the Russians have over- or under-estimated the reserves [illegible] and gas fields. The company will also estimate how much the initial inves[illegible] how long this will take. The same estimates will be made for the gas [illegible] tender followed the shelving of an earlier pre-feasibility [illegible] the cancellation of the second [illegible] (BA Report, 1993b, p.144) [illegible] involvement in hydrocarbon development [illegible] probably not be justified without [illegible]

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Thompson labels the Sakha Republic a "neat canny place", [illegible]

3.3.2.2 Other countries.

Paik (1993, p.304) reports that the Sakha Republic has conducted preliminary negotiations with the Harbin Gas Company (HGC) of China who are interested in purchasing 5 BCM per annum for the Harbin district. Merenkov *et al.* (1993, p.22) suggest that Sakha may be exporting 6-7 BCM per annum to China by 2000-2005. China had been a glaring omission in the original Vostok Plan.

Currently, there are three JVs involved in exploration in the republic. Maxus Energy Corp. of Dallas / Houston, Texas, are evaluating three promising areas (total of 12.5 million acres) with *Yakutskgeofizika* in the Lena-Anabarian, Subverkhoyanian and Subpotomian oil and gas regions. This is a four-year program with a minimum expenditure of $1.5 million (Oil & Gas Russia, Central Asia and the Caucasus, 1994, p.39). ÖMV, the Austrian state-controlled energy concern, formed a JV (called "Takt") with *Lenaneftegazgeologiya* in August 1991. It is exploring two blocks with a combined area of 14,000 km² (Petroconsultants, 1993) in the Nepa-Botuobian and West Vilyuyan regions. Over the next five years over $30 million will be spent on this work and it is reported that they are examining a pipeline proposal (to supply Lensk with gas) (Thompson, 1994). The American geophysicists Fairfield Industries have formed a JV with *Yakutskgeofizika* called "Safairg" (Sakha Fairfield Geophysics). In an operation called "Polar Search", the two are conducting seismic surveys in the Laptev Sea (Leaver, 1993b, p.65; *Oil & Gas Russia, Central Asia and the Caucasus*, 1994, p.38).

5.5.2 Other examples

Park (2003, p. [illegible]) reports that the Sukkia Mayasuki [illegible] [illegible]

with the [illegible] Church (UBCC) of [illegible] [illegible] [illegible] [illegible]

to the [illegible] [illegible]. [illegible] et al. (1998, p.[illegible]) suggest that [illegible] [illegible]

[illegible] in [illegible] 2000-2001 [illegible] [illegible] [illegible] to the [illegible]

[illegible] there are [illegible] [illegible] [illegible] [illegible] [illegible]

of [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

[illegible] to the [illegible] [illegible] [illegible] [illegible] [illegible]

This is [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

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[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

[illegible]

Chapter 4

Environmental Characteristics

Of Central Sakha Republic

4.1 INTRODUCTION

This chapter presents an examination of environmental aspects of central Sakha[1], where the republic's two natural gas 'storehouses' are located. Although there may well be significant gas reserves in the republic's far northwestern districts, it is doubtful whether exports from this area would ever occur on a comparable scale to those planned from the Nepa-Botuobian and Vilyuyan regions. Within the central region, special attention will be paid to a narrow 'corridor' along which natural gas could be transported from the republic to markets outside the Russian Federation. In the presented scenario, gas would be piped not to the south, as has been proposed in recent years by the Japanese and Koreans, but to the east towards the Pacific port of Magadan. The pipeline(s) would cross most of Central Sakha, the northernmost part of Khabarovsk Kray and possibly the extreme southwestern part of Magadan Oblast'. In Magadan, or nearby at the port of Okhotsk, the gas would be liquefied and transshipped to LNG tankers for direct delivery to markets.

As mentioned in the previous chapter, it is not the first time this route has been suggested. In 1970, A.Kosygin, then Soviet prime minister, recommended that the pipeline for the Yakutia Gas Project should be laid from central Yakutia to Magadan (Egyed, 1983, p.63). In his view, this was preferable to laying a pipeline straight to Sakhalin[2]. He claimed that Sakhalin gas reserves (proven) were far outweighed by Yakutian reserves and therefore, in the words of Peter Egyed:

"....although the cost for the two alternative routes was the same, Japan would have had access to a much larger supply of gas under the Yakutsk - Magadan scheme." (1983, p.64).

Verification of larger Sakhalin reserves in late 1970 put an end to the Magadan scheme.

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[1]Broadly speaking between 59°N and 65°N.

[2]On Sakhalin Island, the pipeline would link up with another pipeline laid direct to Hokkaido.

4.2 ENVIRONMENTAL CHARACTERISTICS

An examination of the general characteristics of the area through which the pipeline might pass will be followed (in chapter 5) by suggestions regarding the pipeline route (right-of-way) as well as construction and operating regimes, taking into account these characteristics as well as past and current research into gas pipelines in permafrost environments. If Magadan is selected as the pipeline termination point, at least 65% of the route would lie within the Sakha Republic. The figure would be 80% if Okhotsk were chosen. For this reason among others, the emphasis will be almost exclusively upon information regarding the Sakha Republic portion of the route.

The aim here is to provide details on the human geographical features (e.g. rural population and economic activities, road and river transport) and the physical geographical features (e.g. climate, relief, vegetation, seismicity, permafrost and periglacial processes) that typify the region (shown in Fig.4.1) through which the gas pipeline(s) might pass. The physical characteristics, particularly details of local permafrost and periglacial processes, will be examined in greater depth. This is because the interaction between a pipeline and surrounding soils is the crucial factor determining the overall integrity of the environment and stability of the pipeline. This is most critical in a permafrost environment where the relationship between the two is symbiotic. The pipeline depends upon the ground in which it is laid for stability, but this stability can only be maintained with sound construction and operation of the pipeline. Thus the pipeline, once installed, determines whether ground stability is altered and subsequent damage occurs (see also Ferrians, 1984, p.99; Vilchek & Bykova, 1992; Williams, 1989, p.43).

4.2.1 Human geography.

a) Rural native population:

Other than a large number of immigrant inhabitants, for example Russians (50.3 % of Sakha's total population in 1989), Ukrainians and Belorussians, the population of central Sakha consists largely

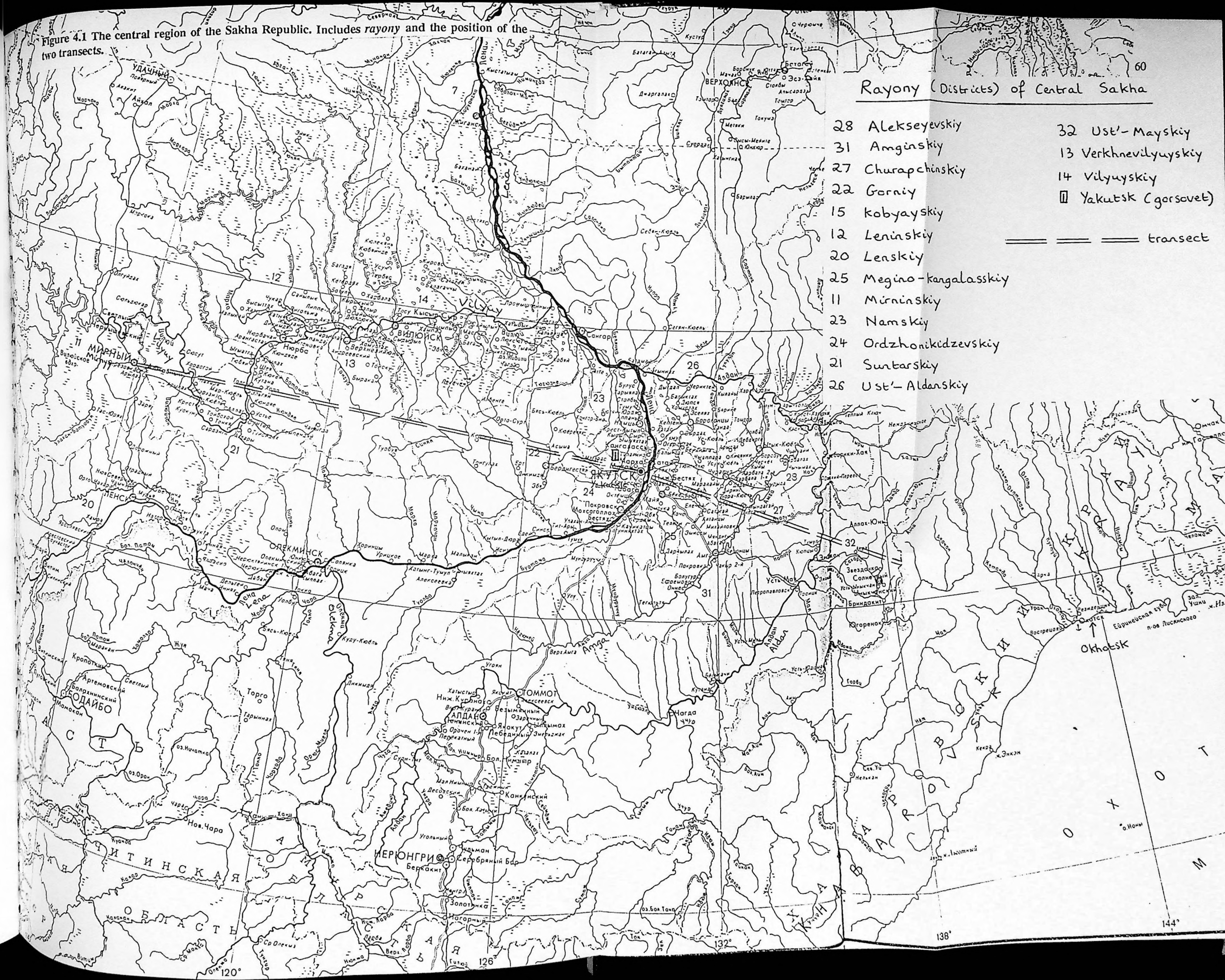

Figure 4.1 The central region of the Sakha Republic. Includes *rayony* and the position of the two transects.

of Yakuts[3] (365,000 or 33.4 % of the population in 1989). A group of central Sakha Yakuts is shown in Fig.4.2. Wixman (1984, p.220) designates these as South Yakuts, horse and cattle breeders, as opposed to the predominantly hunting, fishing and reindeer breeding North Yakuts. The Evenki are also present in significant numbers. Wixman (1984, p.65-66) also designates those of central and southern Sakha as South Evenki, who have taken on traditional Yakut horse and cattle breeding. Many Evenki have been assimilated by the Yakuts. Small numbers of Eveny also inhabit this region. Table 4.1 contains population figures for the *rayony* (districts) of central Sakha.

Table 4.1

Population figures for the *rayony* of central Sakha (1990)

Rayon	Total population (1000s)	Urban	Rural
Alekseyevskiy	16.5		16.5
Amginskiy	16.0		16.0
Churapchinskiy	18.8		18.8
Gorniy	10.2		10.2
Kobyayskiy	20.2	9.8	10.4
Leninskiy	28.9	12.2	16.7
Lenskiy	50.4	41.3	9.1
Megino-Kangalasskiy	32.2	4.0	28.2
Mirninskiy	53.9	47.9	6.0
Namskiy	18.7		18.7
Ordzhonikidzevskiy	35.8	19.2	16.6
Suntarskiy	26.6		26.6
Ust'-Aldanskiy	21.9		21.9
Ust'-Mayskiy	20.5	16.4	4.1
Verkhnevilyuyskiy	21.1		21.1
Vilyuyskiy	28.6	15.8	12.8
Yakutsk (*gorsovet*)	222.3	215.5	6.8
TOTAL	642.6	382.1	260.5

Source:
Goskomstat RSFSR, 1990, p.45-50.

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[3]The Yakuts are not recognized as one of the 26 Russian Northern Minorities since they number approximately 328,000. In comparison, the Yukagirs, who inhabit parts of northeastern Sakha numbered only 1140 in 1989 (Vakhtin, 1992, p.8).

Figure 4.2 Indigenous inhabitants of central Sakha. A group of Yakut farmers take a break from harvesting. Source: *Nov' Yakutskogo Sela*, 1988.

b) Animal breeding and herding:

Though it may seem obvious, the central districts represent for the Yakuts the heartland of the republic for this is where most of the cattle- and horse-breeding takes place. Both of these are traditional Yakut economic activities which were brought from southern Siberia, from where they migrated during the Middle Ages (Vitebsky, 1990b, p.304). As Mel'nikov and Pavlov (1982, p.169) have shown, central Sakha is rich in land suitable for cultivation. Approximately 60% of hay production in these lowlands comes from fertile *alas* formations (Mote, 1983a, p.32), the best and largest examples of which are found in central Sakha. Thus horses and cattle benefit from the lush vegetation and pastures of the *alas* relief that is so characteristic of the valleys and plains of the Lena, Vilyuy and Aldan rivers, as shown in Fig.4.3. Both cattle and horse breeding are concentrated along the Vilyuy River and around Yakutsk, as shown in Fig.4.4.

Reindeer herding is traditional only for the smaller native groups, the true indigenous people of Sakha[4], who practice this activity in the more mountainous terrain of the south and the mountains and tundra of the north. A very small number of domesticated reindeer are to be found in central areas. Only five small reindeer *sovkhozy* are shown in central Sakha in the 1989 *Atlas Sel'skogo khozyaystva Yakutskoy ASSR* (Atlas of Agriculture of the Yakut ASSR, p. 72-73). At January 1st 1986, these had between 100 and 850 heads each (see Fig.4.5). Fig.4.6 shows a small herd in central Sakha. There are only three large herds of wild reindeer in the republic and the largest two, the Lena-Olenyok and Yana-Indigirka, are confined to the far north (Syroyechkovskiy *et al.*, 1990, p.122).

c) Transport:

As with pipelines, the republic's transport network is not well developed. North (1990, p.191) cites Sakha as having 0.04 km of railway per 1000 km^2, though this figure has increased marginally with

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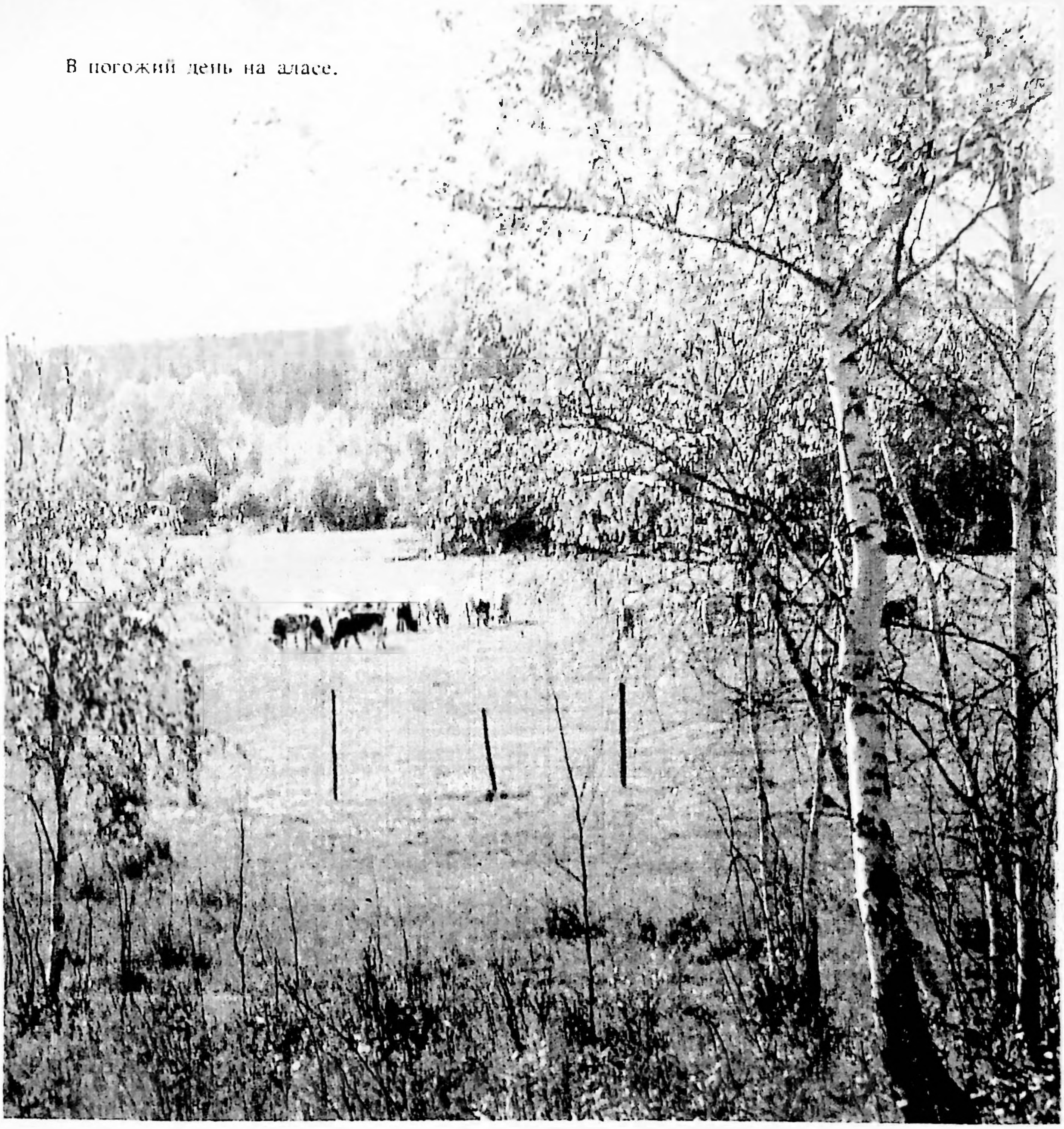
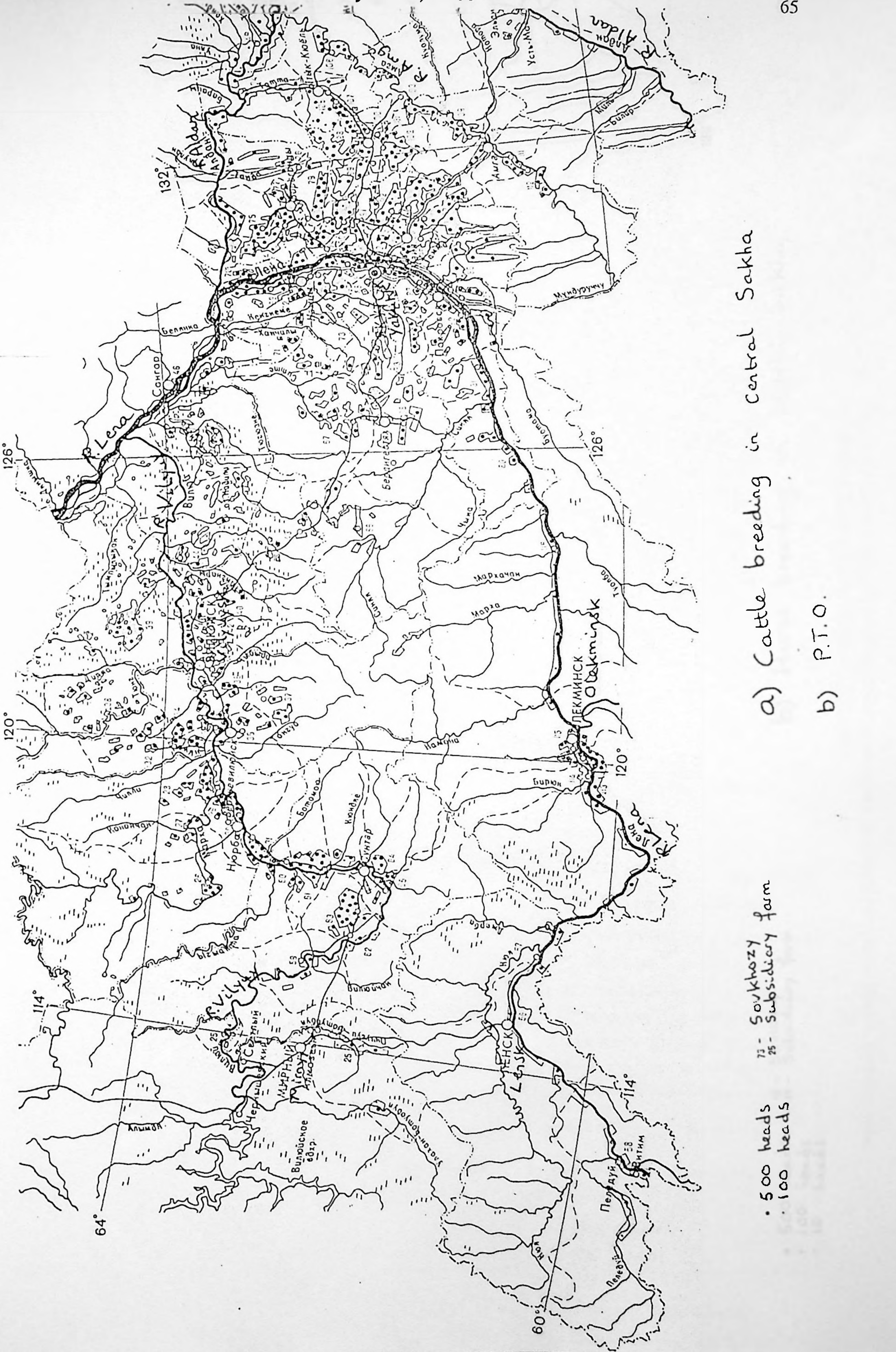
[4]For example, the Eveny and Evenki.

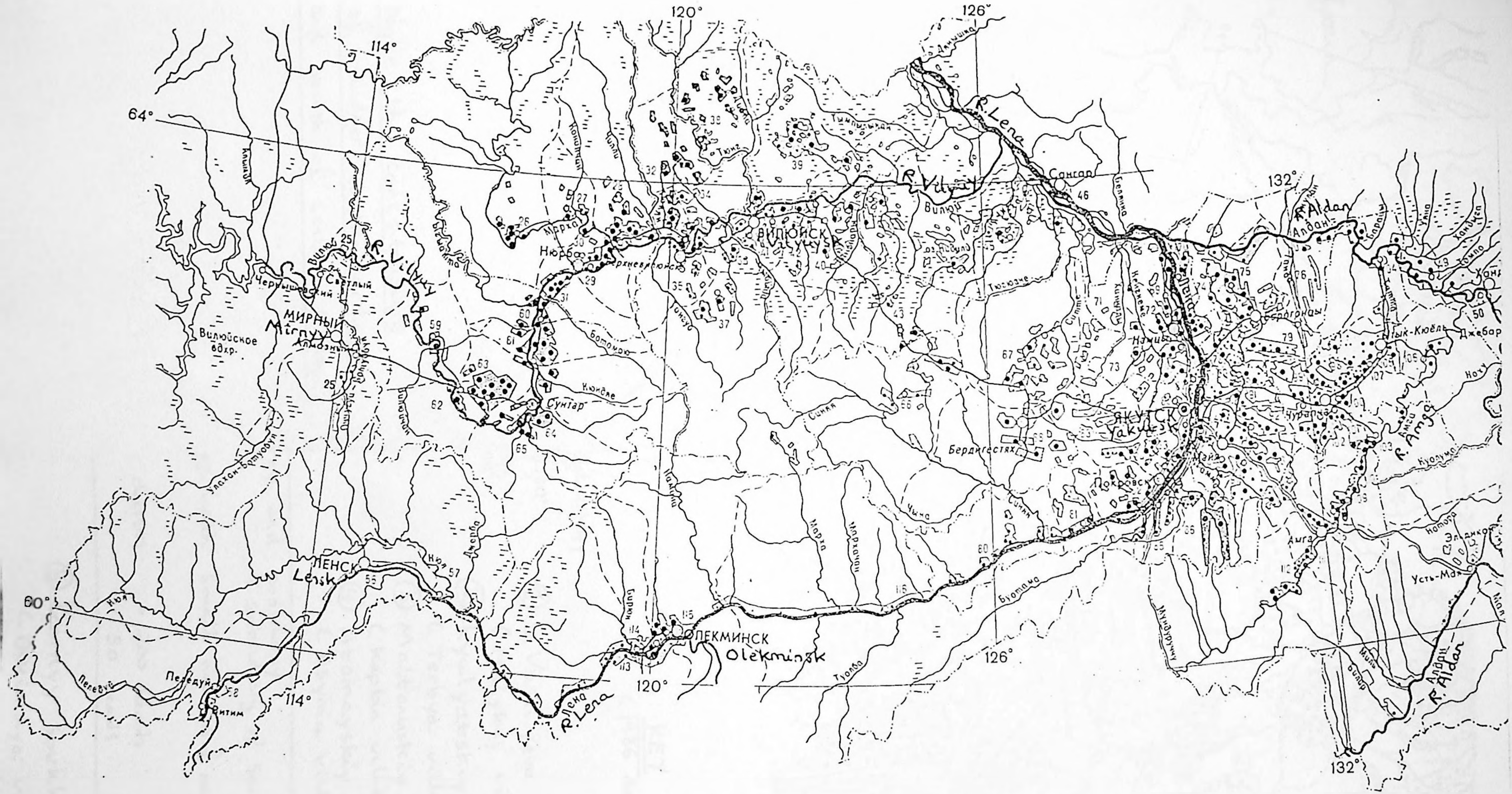
Figure 4.3 The fertile alas. Cattle graze on lush grass in an alas depression. Source: *Nov' Yakutskogo Sela*, 1988.



В погожий день на аласе.

Figure 4.4 The distribution of horse breeding (a) and cattle breeding (b) in central Sakha. Source: *Atlas Sel'skogo Khozyaystva Yakutskoy ASSR*, 1989.





• 500 heads
• 100 heads
· 10 heads

95 – Sovkhozy
25 – Subsidiary farm

b) Horse breeding in central Sakha

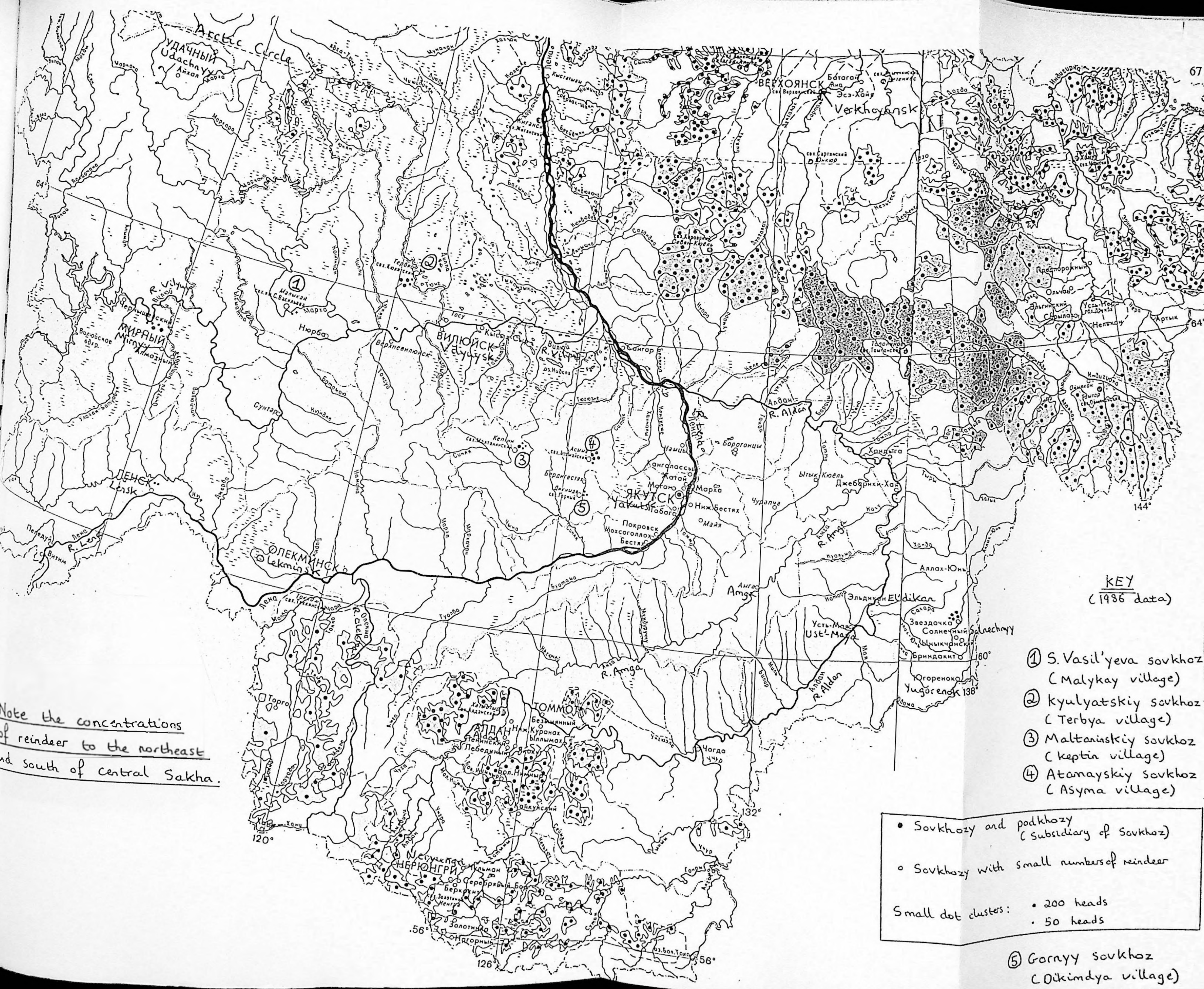
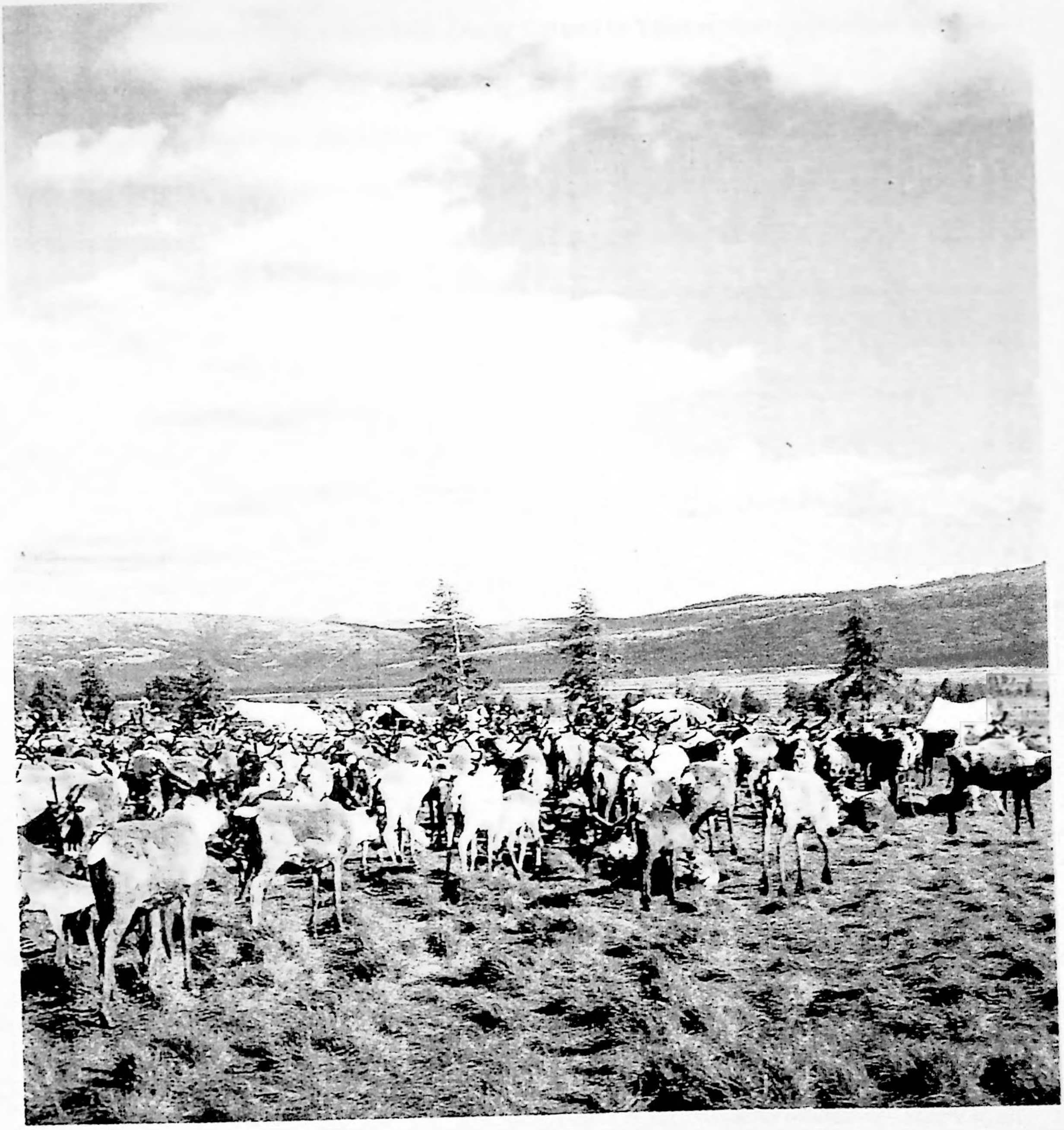


Figure 4.5 Distribution of reindeer herding *sovkhozy* in central in central Sakha. Source: *Atlas Sel'skogo Khozyaystva Yakutskoy ASSR*, 1989.

Figure 4.6 Reindeer in central Sakha. A small herd of reindeer with their herders' tents in the background. Source: *Nov' Yakutskogo Sela*, 1988.



some progress in the construction of the AYAM (Amur - Yakutsk mainline) railway[5]. This remains the only railway in the republic.

Sakha is better served by roads, as shown in Fig.4.7, though there was only 1.5 km of road per 1000 km^2 in 1990. The vast majority of these are confined to the southern central districts of the republic. However, relative to the republic's size, there are very few long-distance all-weather roads. The most significant of these is the Never (Amur Oblast') to Yakutsk road (approximately 1000 km long), beside which the AYAM will operate once completed. This is the only 'state-level' (*obshchegosudarstvennogo znacheniya*)[6] road in the entire republic. However, the only asphalt section of the road is the 80 km stretch between Aldan and Tommot, the remainder being gravel. The longest asphalt road in the republic is the 90 km Yakutsk to Mokhsogollokh highway. The only other asphalt road is that between Yakutsk and the coal mining centre of Kangalassy, covering a distance of some 30 km. West of Yakutsk, the sparse network is dominated by the Mirnyy to Yakutsk road, most of which is 'regional-level' (*oblastnogo znacheniya*) road according to recent maps. The road runs close to the Vilyuy River via Suntar as far as Vilyuysk. Thereafter, it runs direct to Yakutsk via Berdigestyakh. Also noteworthy is the ca.200 km road from Lensk, a town largely associated with oil and gas exploration and drilling in the Nepa-Botuobian region, to Mirnyy. The 1987 map of the *Yakutskaya ASSR* (*Administrativno-Territorial'noye Deleniye Yakutskoy ASSR*) shows this as being a 'local-level' (*mestnogo znacheniya*) road. According to Intera & *Sakhaneftegaz* (1993), this is now an all-weather year-round highway.

To the east of Yakutsk, the network is slightly less sparse with quite an extensive network of 'regional-level' and 'local-level' roads serving the relatively populous area immediately north and east of the city. The most important road is that between Yakutsk and Ust'-Maya (which lies beside the Aldan River). The road is 'republic-level' (*respublikanskogo znacheniya*) as far as Amga. A 'local-

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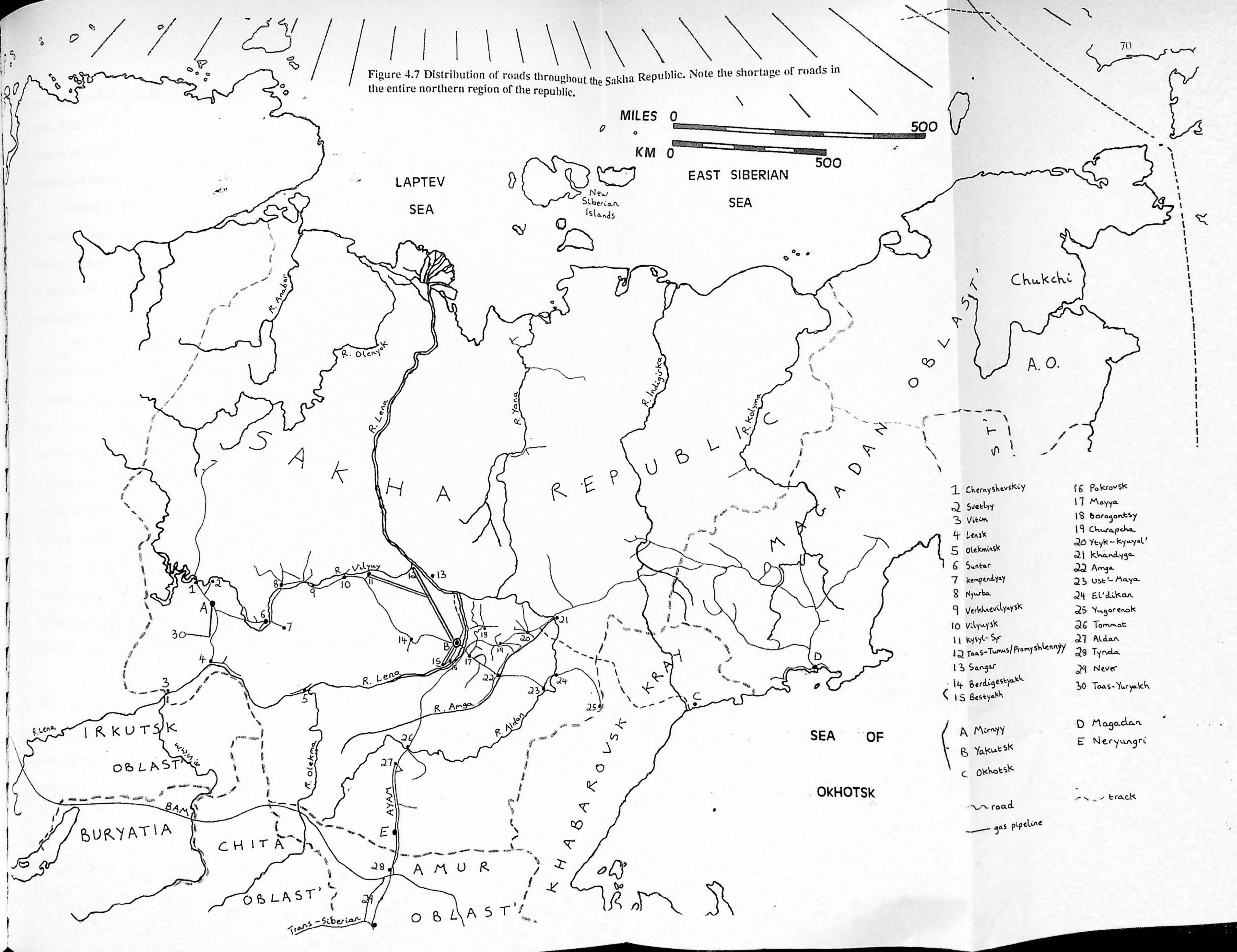
[5]The railway has apparently reached Aldan (Thompson, 1994), leaving another 450 km until it reaches Nizhne-Bestyakh (on the opposite bank of the R.Lena from Yakutsk). One day the line will link Yakutsk with the BAM (Baikal - Amur mainline) railroad.
[6]There are four road categories in the Sakha Republic. They are: i. state-level (*obshchegosudarstvennogo znacheniya*); ii. republic-level (*respublikanskogo znacheniya*); ii. regional-level (*oblastnogo znacheniya*); iv. local-level (*mestnogo znacheniya*).

Figure 4.7 Distribution of roads throughout the Sakha Republic. Note the shortage of roads in the entire northern region of the republic.



level' road links El'dikan and Yugorenok, the latter straddling the republic's border with Khabarovsk Kray. Some recent western maps show a stretch of road connecting Ust'-Maya and El'dikan, a distance of some 60 km, thus confirming an unbroken link between Yakutsk and the republic's southeastern border.

During winter the road network is augmented by so-called 'winter roads' which make use of the region's dense network of rivers, most of which are ice-covered for eight months of the year. Vehicles gain access to parts of the republic that during summer would be cut off when dirt roads are turned into impassable quagmires. This explains why river transport plays such an important role during the short summers.

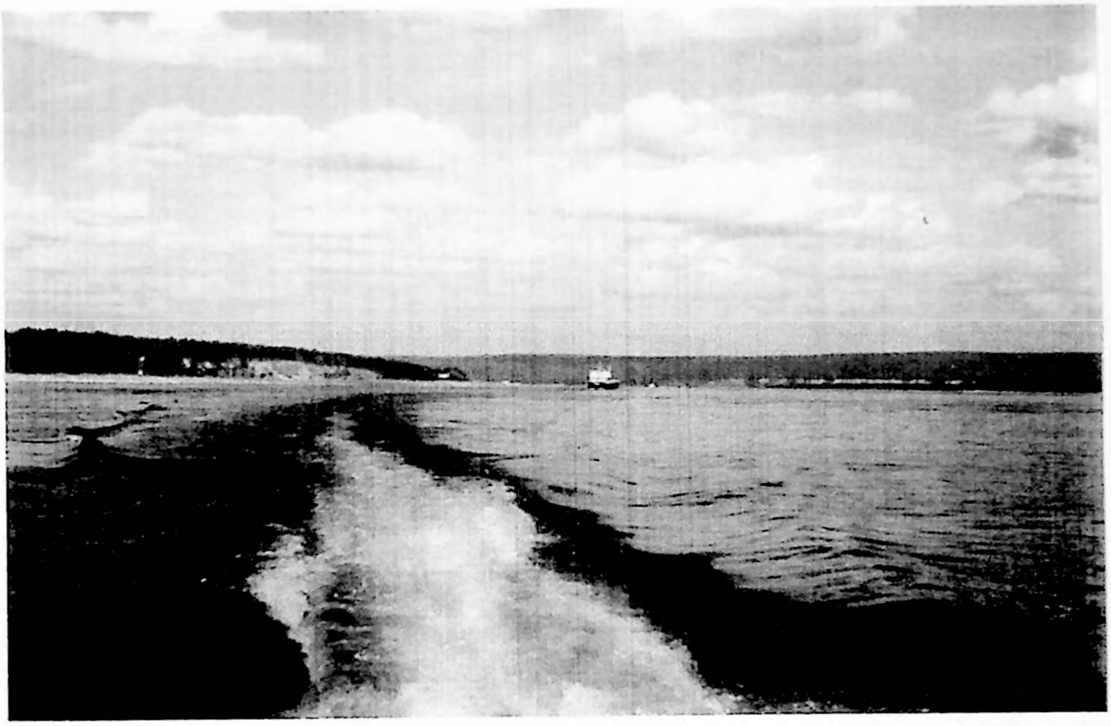
The vast River Lena, shown in Fig.4.8, flowing 4500 km from the mountains of the Baikal Range to Tiksi on the Laptev Sea, is Sakha's "Lifeline" (Mote, 1987, p.58). Most of the imported consumer products and oil products arrive on shallow-draught cargo vessels and tankers, such as those shown in Fig.4.9, which come from Osetrovo (where freight is transshipped from the BAM). The Lena provides access to the Vilyuy, Aldan and Olekma as well as hundreds of other smaller tributaries, not to mention the entire north coast of the republic, where the Yana and Indigirka basins rely almost entirely upon supplies that are delivered via the Lena and the coastal lanes of the Laptev and East Siberian seas (see Fig.4.10). Other than in-shipments of consumer and oil products and out-shipments of natural resources, such as coal and timber, movements on the rivers are on a relatively small scale. Passenger services are operated throughout the short navigation on the Lena, Vilyuy and Aldan using fleets of small hydrofoils and a number of larger slower vessels (see Fig.4.11). Without these, passenger movements would be severely restricted.

4.2.2 Physical characteristics.

a) Climatic conditions:

Central Sakha has the most continental climate in the world. Annual temperature ranges, as already indicated in chapter 3, are unparalleled anywhere else. At Oymyakon, which is marginally northeast of the central region, the average January temperature is -55°C, while in July it is 18°C, giving an

Figure 4.8 The Lena River. A view of the Lena south of Yakutsk taken from the stern of a *Raketa* hydrofoil. In the distance, a freighter makes for Yakutsk. Source: author's photograph.



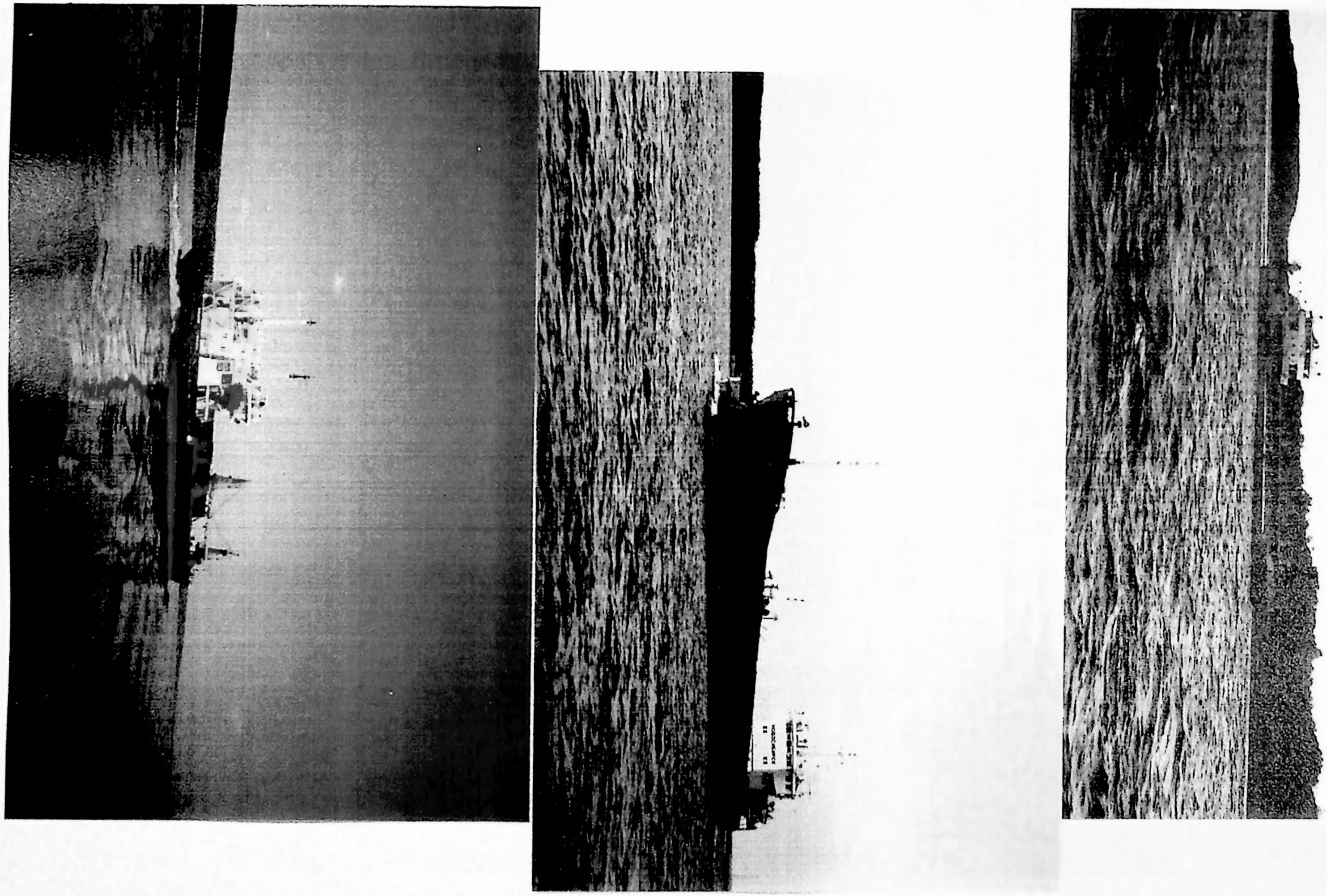
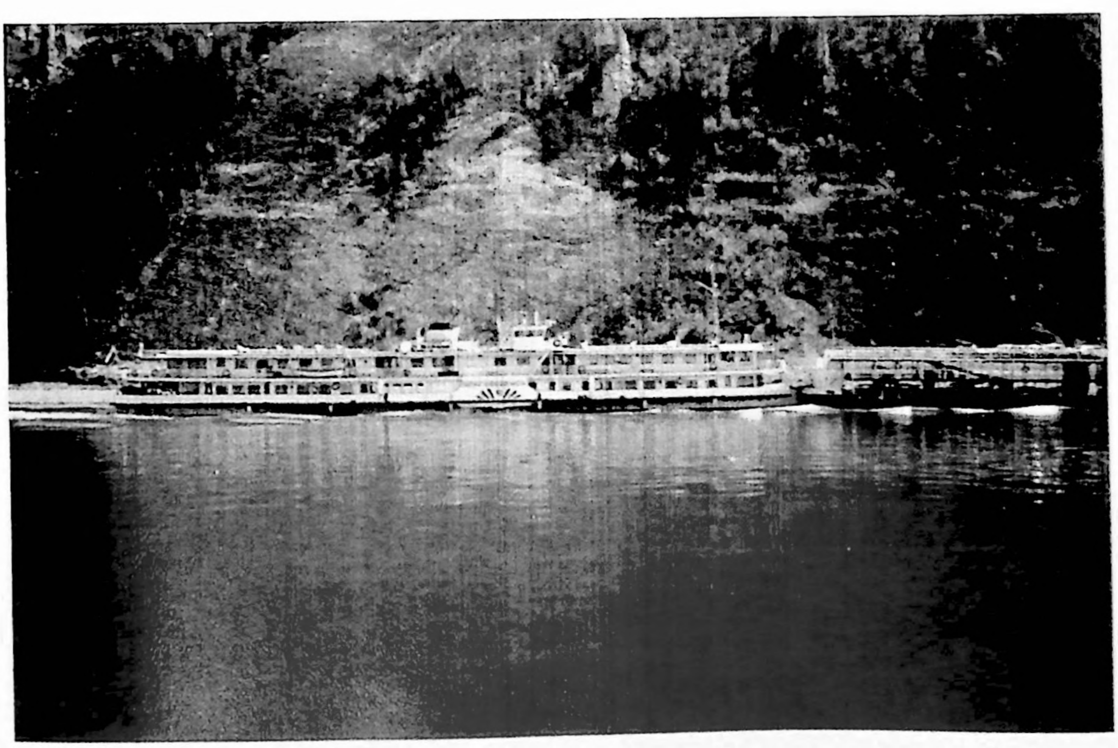


Figure 4.9 Lena river vessels. From top to bottom. A shallow-draught tanker used to import oil. The freighter 'Novosibirsk' anchored mid-river. A general cargo vessel heads north to Yakutsk. Source: author's photographs.

Figure 4.10 Supplies to Sakha's far north. One of the latest generation of shallow-draught freighters, the '60 Years of the Yakut ASSR', in the Lena delta, heading for Tiksi and the Yana delta. Note its proximity to the shoreline. In late summer, the navigation channel in the Lena delta becomes very shallow indeed. Source: author's photograph.

Figure 4.11 Passenger transport on the Lena. The passenger vessel 'Blagoveshchensk' heads for Osetrovo. The vessel is pushing a car transporter. Source: author's photograph.



annual range of 73°C (Suslov, 1961, p.128). The figures for Yakutsk, the most representative meteorological station of the central region, are -48°C, 17°C and 65°C respectively (Pryde & Mote, 1990, p.37). The record minimum at Oymyakon is -71°C, the coldest temperature ever recorded outside Antarctica. Pryde & Mote quote Yakutsk's coldest recorded temperature as -64°C, while Suslov gives -69°C.

The winter climate is determined by the Siberian high pressure system. There is virtually no cloud and wind formation and thus very little precipitation. 100 mm of snow on the ground in January is the norm (Koutaniemi, 1985, p.425). Extreme radiation results in supercooling of the lower atmosphere, which is further accentuated by temperature inversions. Conversely, in summer, daytime temperatures are relatively high (the region is not influenced by the oceans' moderating effects). Precipitation is confined largely to the summer months, though this rarely exceeds 140 mm (June to September). Evaporation in the summer is almost three times the amount of moisture received (Koutaniemi, 1985, p.425). It is thus easy to understand why the region is extremely arid. Maximum and minimum monthly temperatures and average monthly precipitation figures for a number of Sakha's settlements, including the central settlements of Vilyuysk, Olekminsk and Yakutsk are shown in Fig.4.12.

b) Relief:

Central Sakha forms part of the Lena Basin. Here, the Lena River flows at an altitude of about 100 m above sea-level. Fig.4.13 gives an overall impression of the region's relatively low relief. This is in stark contrast to the relief of the south and north, where mountains reach altitudes well in excess of 2000 m (in the Aldan Uplands of the south) and 3000 m (in the Cherskiy Mountain Range of the northeast). The highest altitudes in the central region (up to 2400 m) are found in the Sette-Daban Range which lies on Sakha's eastern border with Khabarovsk Kray. However, for the most part altitudes rarely exceed 400 m. Other than south of the Lena, heights exceeding 500 m are not encountered until well beyond (east of) the Aldan River. Once east of the Sette-Daban Range, there [illegible] annual range of 75°C (Suslov, 1961, p.[illegible]). The figures for [illegible], the most representative meteorological station of the central region, are [illegible] respectively (Pryde & Mote, 1990, p.[illegible]). The record minimum at [illegible] is [illegible]; outside Antarctica, Pryde & Mote quote [illegible] temperature as [illegible] below [illegible].

[illegible]

Relief

[illegible] form part of the [illegible] Basin. Here, the [illegible] River flows at an altitude of about 100 [illegible] Fig.[illegible] gives an overall impression of the region's relatively low relief. This is in [illegible] contrast to the [illegible] of the south and north, where mountains reach altitudes well in excess of [illegible] m (in the [illegible] Uplands of the south) and 2000 m (in the Chersky Mountain Range of the [illegible]). The highest elevations in the central region (up to 2400 m) are found in the Sette-Daban Range which lies on [illegible] eastern border with Khabarovsk Krai. However, for the most part altitudes rarely exceed 400 m. Other than south of the Lena, heights exceeding 500 m are [illegible] until well beyond [illegible] the Aldan River. [illegible] of the Sette-Daban Range, there

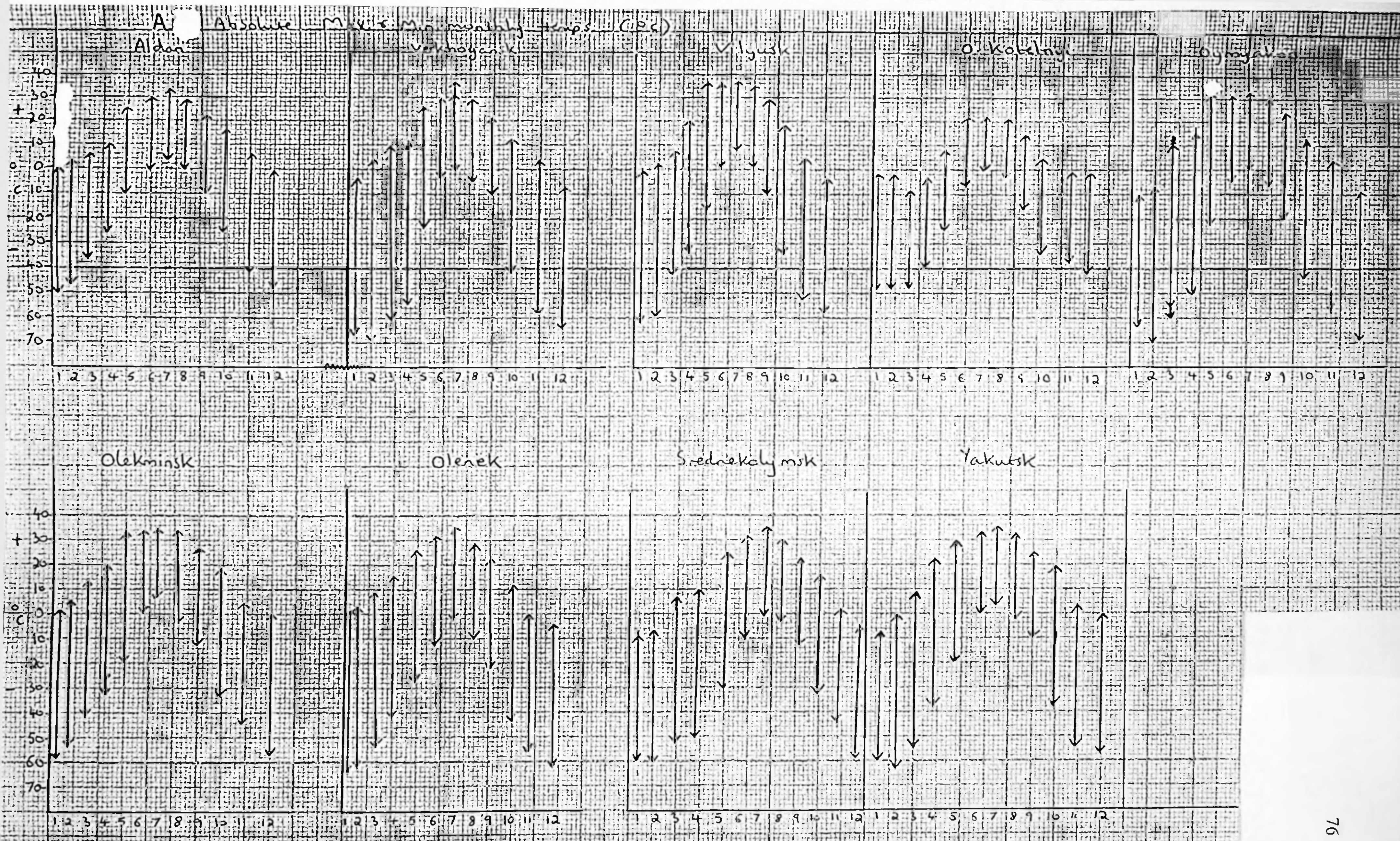


Figure 4.12 Climatic characteristics of the Sakha Republic. Absolute maximum and minimum monthly temperatures (a) and average monthly precipitation (b) for selected settlements. Aldan, Vilyuysk, Olekminsk and Yakutsk are central or southern settlements. Source: *Atlas Yakutskoy ASSR*, 1981.

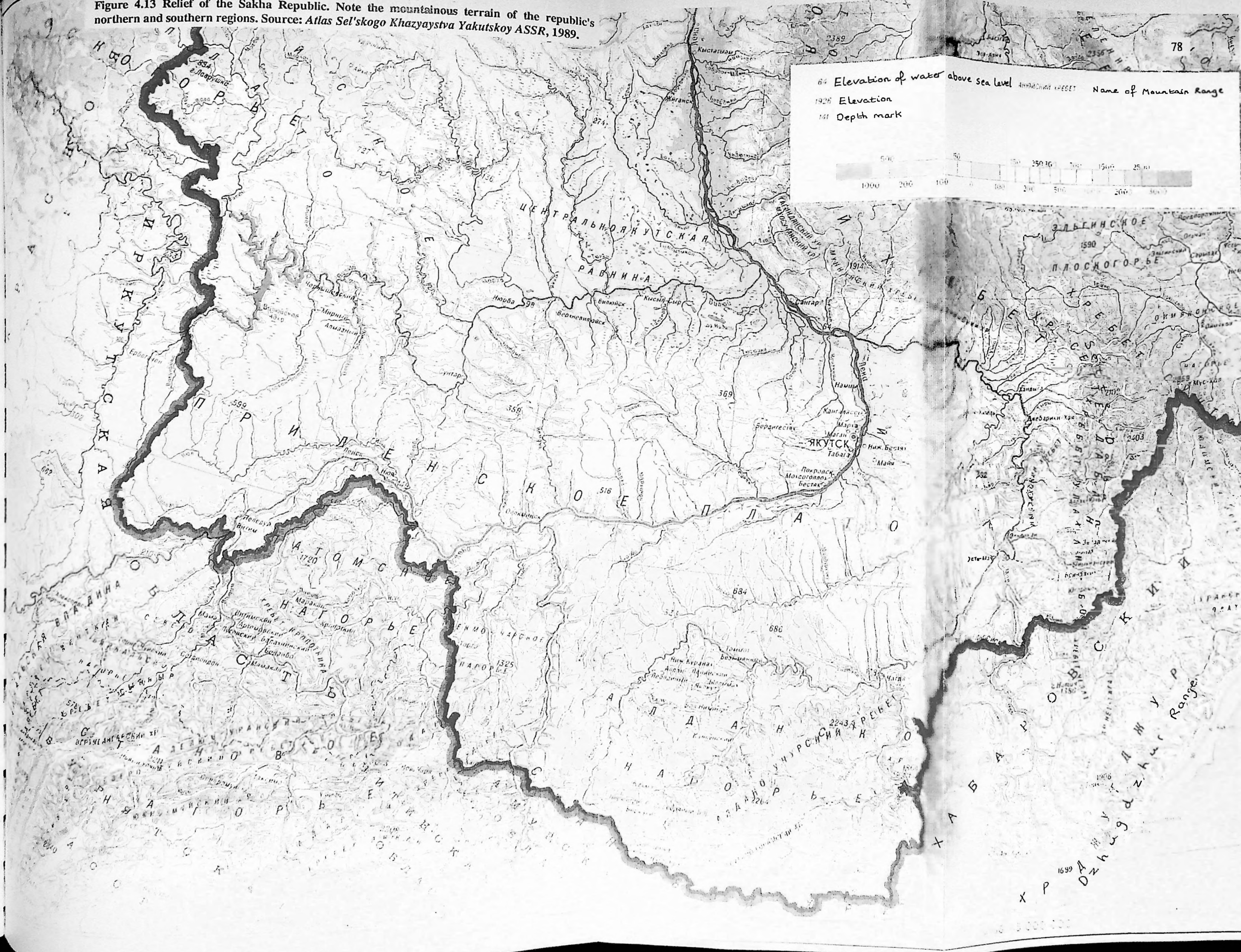


Figure 4.13 Relief of the Sakha Republic. Note the mountainous terrain of the republic's northern and southern regions. Source: *Atlas Sel'skogo Khazyaystva Yakutskoy ASSR*, 1989.

is a sharp drop in altitude towards the coast of the Sea of Okhotsk. In summary, there is a gentle trend towards higher altitudes as one progresses eastwards in this region.

c) Soils and Vegetation:

The valley of the Lena River contains sandy alluvial deposits, described by Vasil'yev (1993, p.240) as ubiquitous, interrupted by sandy loams in the upper layers. *Supes* (sandy silt) and *suglinok* (clayey silt)[7] are both common throughout the region. The extreme aridity of central Sakha means that there are fewer swamps than in western Siberia and there is less podzolization. Peaty soils are common on floodplains which tend to be poorly drained. Suslov (1961, p.197) describes four main characteristics of the coniferous taiga here. First, the most common tree is the cold-resistant Dahurian larch (*Larix dahurica*). He describes the forests of East Siberia and Sakha as being "extremely monotonous" (p.139) because all one can see is mile upon mile of larch. Nevertheless pine (especially on sand), birch and aspen are quite common; second, scrub alder (e.g. *Alnus fruticosa*) is the most common form of undergrowth; third, in the drier larch forests, especially in the Vilyuy and Lena valleys and the Lena-Amga watershed, there is often a wide variety of steppe species. This can be attributed to the continental climate (little precipitation and very warm summer temperatures), very little leaching and the presence of carbonaceous soils. The fourth characteristic is that bogs are small and sparse. Meadows have a dense undergrowth of reed grass, sedge and other grasses.

d) Seismicity:

Pryde & Mote (1990, p.43) have defined the most active areas in the Russian Far East as southeastern Kamchatka and the Kuril Islands, the mouth of the Lena River, the Cherskiy Mountains (northeast Sakha) and the Olekma and western Aldan zone (southern Sakha). Earthquakes measuring 7.9 on the Richter Scale have struck this latter zone, through which the BAM railway passes. The

[7]There is no English equivalent of these soil types and so the Russian has been retained. Definitions can be found in the Glossary of Russian Terms and Abbreviations.

[illegible] of the [illegible]. In summary, there is a gentle

[illegible]

[illegible]

[illegible] (1991, p.47), have defined the [illegible] zones in the [illegible] Zone as [illegible] and the [illegible], the [illegible], the [illegible] Mountains [illegible] through which the [illegible] passes. The

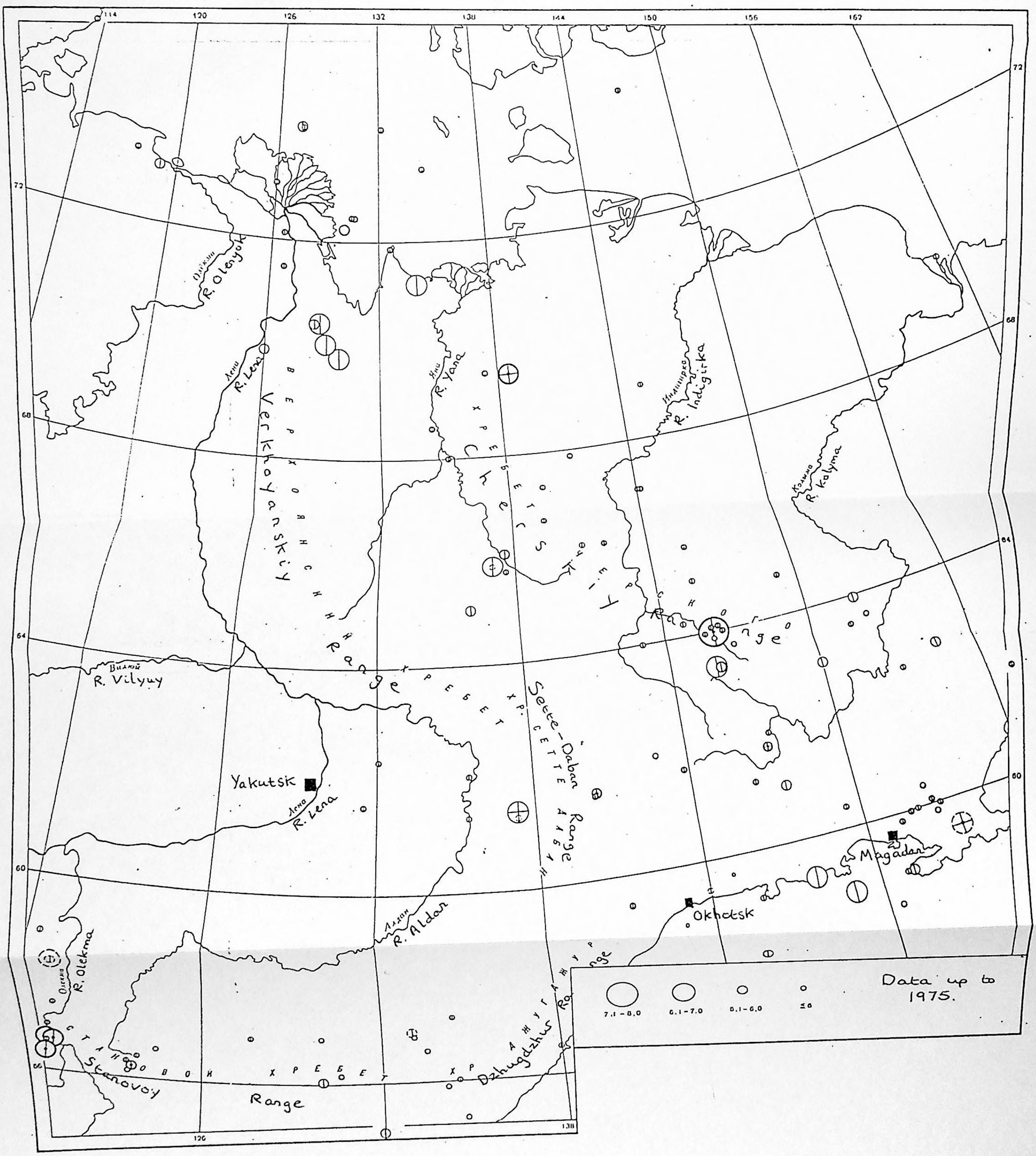
[illegible] Definitions can be [illegible] most active parts of the relatively quiet central region are in the east near the Khabarovsk Kray border. Koz'min & Andreyev (1977, p.339-348) compiled a chronology (1735-1975) of seismic events in Sakha and Magadan Oblast'. The Sette-Daban Range and particularly the Dzhugdzhur Range (see Fig.4.14) have been the most active areas of central Sakha and northern Khabarovsk Kray. Of the 42 earthquakes (average magnitude of 4.9) recorded in these two mountainous areas during the period, the strongest measured 6.6 (Dzhugdzhur Range) in October 1931 (Koz'min & Andreyev, 1977, p.342). The west of the region has experienced virtually no earthquakes or tremors at all.

e) Permafrost and periglacial processes:

The formation of permafrost[8] in central Sakha can be attributed to the failure of the Pleistocene glaciations to reach the area (a result of extreme aridity) as well as even colder temperatures than those common nowadays (Koutaniemi, 1985, p.421). The continuity of permafrost in Sakha is shown in Fig.4.15. The permafrost in central Sakha is deeper than anywhere else on earth, plunging to at least 1.5 km in places. Localized thawing of permafrost will initiate thermokarst processes, involving the *in situ* melting of buried ice, and these will ultimately give rise to *alas* relief, the formation of which is described in more detail in Fig.4.16. Though this thawing was once caused by climatic changes, local changes in external conditions or forest fires alone, human activity is now a major contributory factor, much to the dismay of Koutaniemi (1983, p.428) and Klimovsky & Murzin (1993, p.33). In central Sakha such relief may cover many hundreds of square kilometres, especially on the alluvial floodplains of the Lena River (Klimovsky & Murzin, 1993, p.33). In places, *alas* formations accounts for up to half of the relief. This type of relief can only develop where there are large amounts of ground ice or unconsolidated sediments with a high ice content. Central Sakha easily meets these requirements since the region experiences intensive ice wedge

[8]Defined as a condition which exists below the ground surface, in which the temperature of the material, whatever it may be, has remained below 0°C continuously for more than two years. It is commonly referred to as perennially frozen ground.

Figure 4.14 Distribution and intensity of earthquakes in the Sakha Republic, northern Khabarovsk Kray and Magadan Oblast'. Source: Koz'min & Andreyev, 1977.



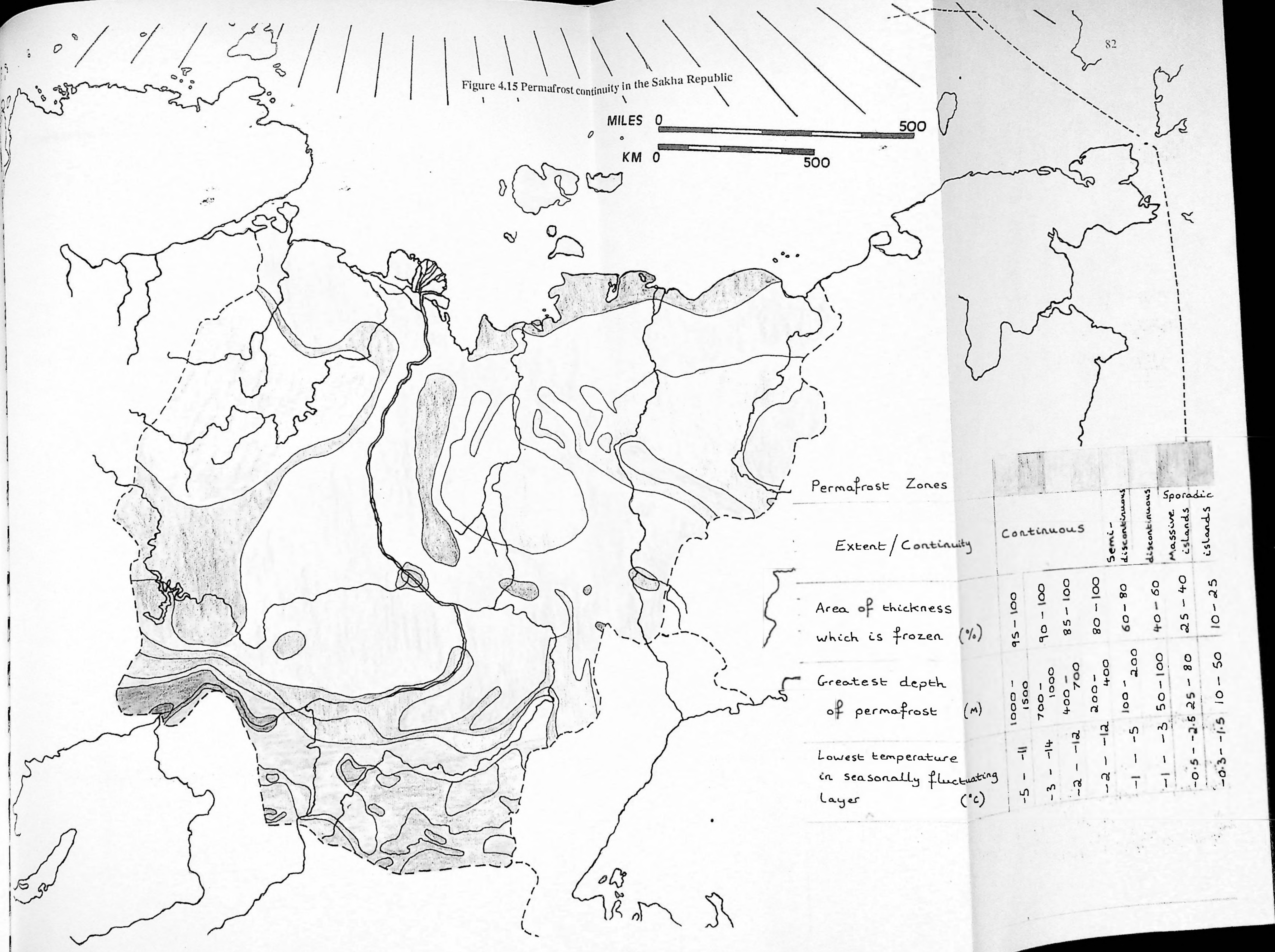


Figure 4.15 Permafrost continuity in the Sakha Republic

Permafrost Zones								
Extent / Continuity	Continuous				Semi-discontinuous	discontinuous	Sporadic: Massive islands	Sporadic: islands
Area of thickness which is frozen (%)	95 – 100	90 – 100	85 – 100	80 – 100	60 – 80	40 – 60	25 – 40	10 – 25
Greatest depth of permafrost (m)	1000 – 1500	700 – 1000	400 – 700	200 – 400	100 – 200	50 – 100	25 – 80	10 – 50
Lowest temperature in seasonally fluctuating layer (°C)	-5 – -11	-3 – -14	-2 – -12	-2 – -12	-1 – -5	-1 – -3	-0.5 – -2.5	-0.3 – -1.5

Figure 4.16 The development of alas relief. Central Sakha example. Source: Koutaniemi, 1985.

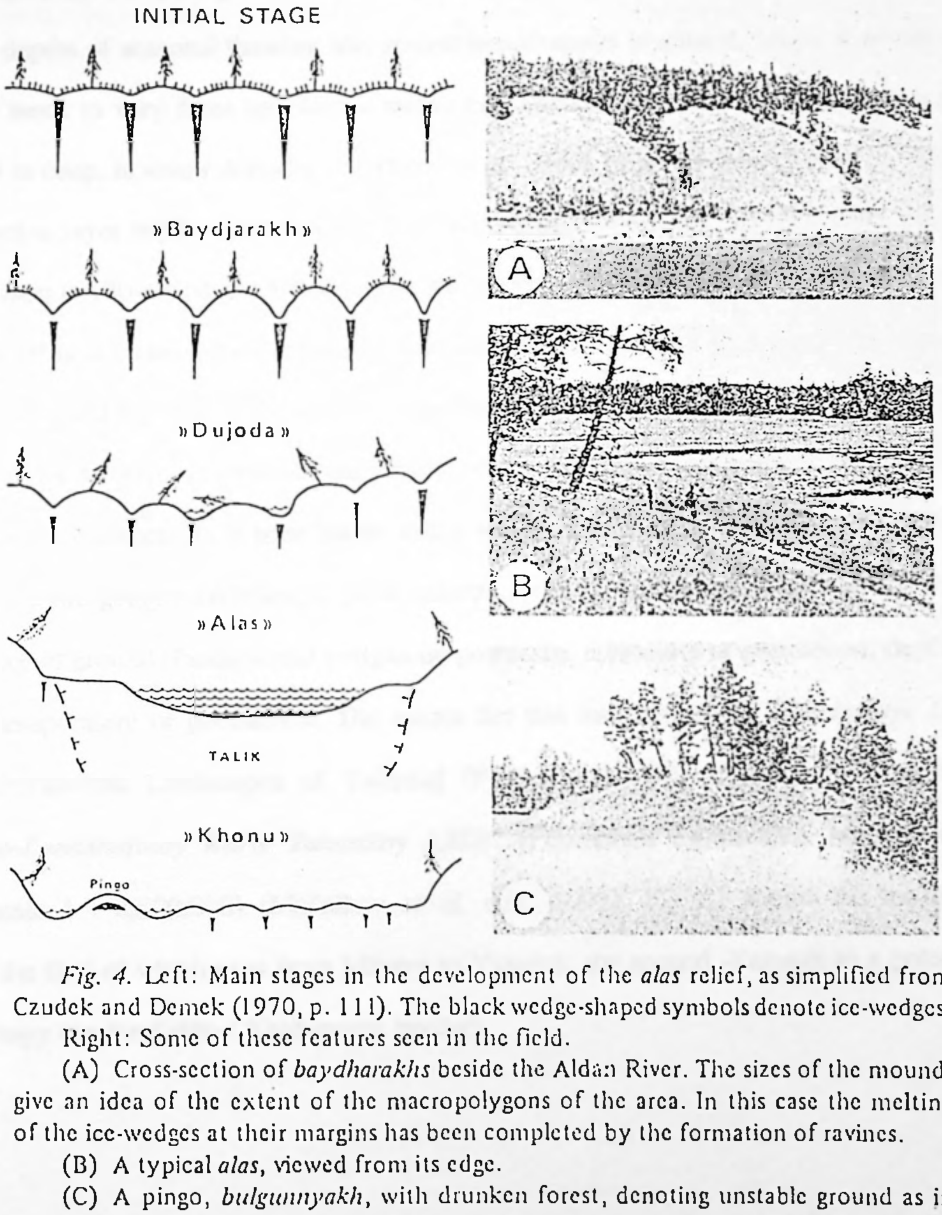


Fig. 4. Left: Main stages in the development of the *alas* relief, as simplified from Czudek and Demek (1970, p. 111). The black wedge-shaped symbols denote ice-wedges. Right: Some of these features seen in the field.

(A) Cross-section of *baydharakhs* beside the Aldan River. The sizes of the mounds give an idea of the extent of the macropolygons of the area. In this case the melting of the ice-wedges at their margins has been completed by the formation of ravines.

(B) A typical *alas*, viewed from its edge.

(C) A pingo, *bulgunnyakh*, with drunken forest, denoting unstable ground as in the previous picture.

Photographs: Leo Koutaniemi, July 1982.

growth in unconsolidated sediments. The distribution of ice wedges in Sakha is shown in Fig.4.17. Some of these may be up to 80 m thick (see Fig.4.18) (Mel'nikov & Pavlov, 1982, p.163).

Other periglacial processes occurring in the region include solifluction (including creep), heaving, rock glaciers and frost shattering. Though the distribution of these processes throughout the republic is far from even, the potential for localized pipeline disruption is evident. Table 4.2 shows the greatest depths of seasonal thawing and ground temperatures in central Sakha. It reveals that the active layer tends to vary from less than a metre, in poorly drained areas of peat and *suglinok*, to more than 4 m deep, in sandy deposits (Fyodorov *et al.*, 1989, p.24; Kamensky *et al.*, 1993, p.322). However, active layer depths rarely exceed 2 m. According to Vasil'yev (1993, p.240), the length of the thaw season is 130-140 days. Taliks, unfrozen layers in permafrost, are common near rivers and lakes. Fig.4.19 is a cross-section of permafrost showing the differences between the levels of the permafrost table and the base of the annually fluctuating layer.

In order to give an overall impression of the typical characteristics of central Sakha's permafrost, two transects have been taken, along which details on the following are given: terrain type, stratigraphic-genetic complexes, predominant cryogenic textures and ground ice formations, volume of ice in ground, fundamental periglacial processes, continuity of permafrost, depth of active layer and temperature of permafrost. The source for this information is *"Merzlotnyye Landshafty Yakutii"* [Permafrost Landscapes of Yakutia] (Fyodorov *et al.*[9], 1989) and its accompanying *"Merzlotno-Landshaftnoy Karte Yakutskoy ASSR"* [Permafrost Landscapes Map of the Yakut ASSR] (scale 1 : 2,500,000) (Mel'nikov *et al. eds.*, 1991). Fig.4.1 shows the location of the transects, the first of which runs from Mirnyy to Yakutsk, the second, Yakutsk to a point northeast of Solnechnyy (on the Sakha / Khabarovsk border).

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[9]Fyodorov and colleagues are members of the *Institut Merzlotovedeniya* (Institute of Permafrost Studies), Yakutsk.

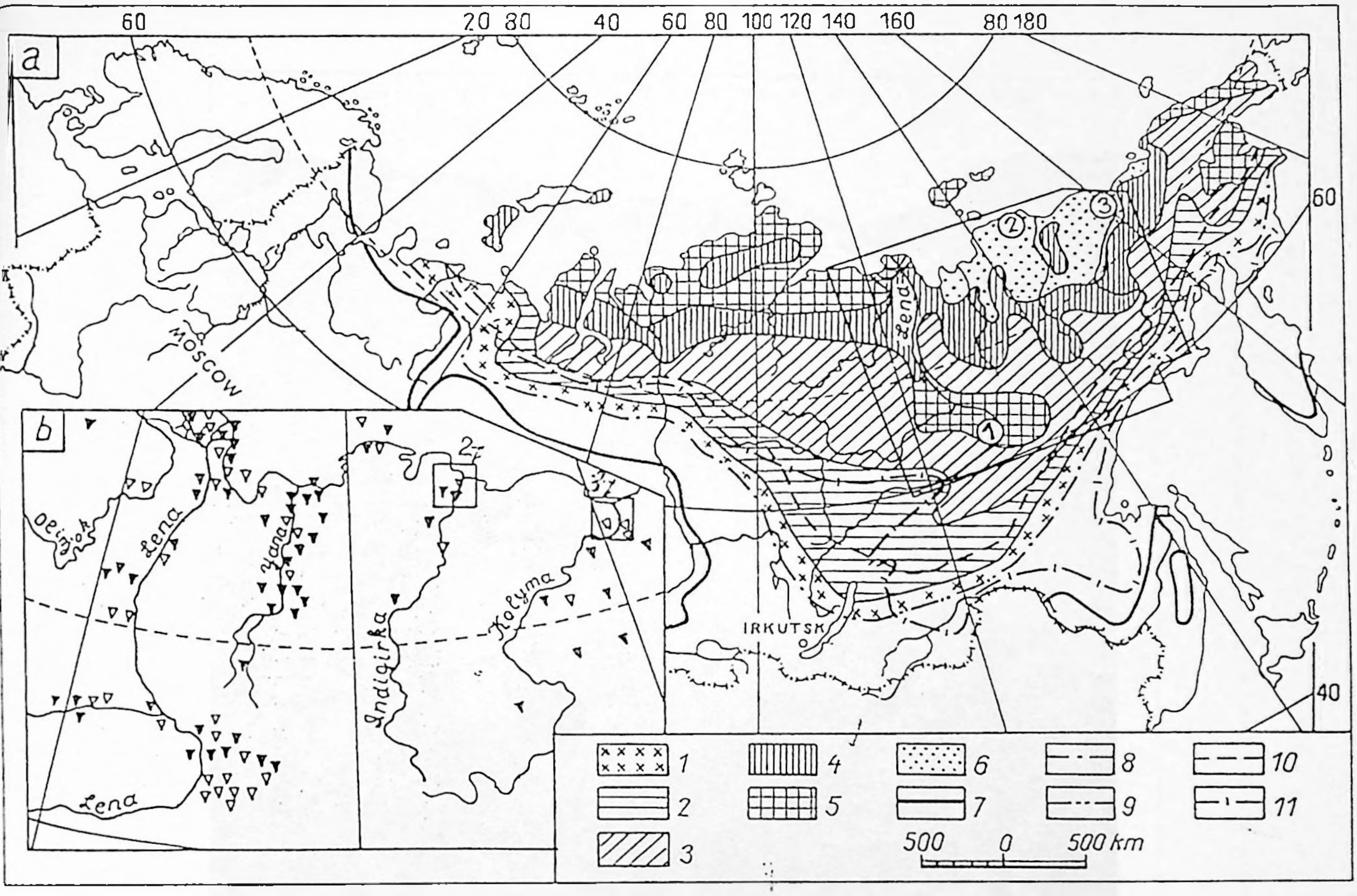
period in consolidated sediments. The distribution of the wedges in Siberia is shown in Fig.4.17. [illegible] wedges that may be up to 50 m thick (Fig.4.11) (Geocryology of the USSR, 1988, p.160).

Other periglacial processes occurring [illegible] forming ice plants and frost shattering. [illegible] [illegible] the [illegible] the [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] and [illegible] the surface and thickness of the [illegible]

In order to give an overall impression of the typical characteristics of Russian Subarctic permafrost, two transects have been taken, along which details on the following are given: terrain and vegetation-zonal categories, predominant cryogenic deposits and ground ice formations, content of ice in ground, fundamental periglacial processes, continuity of permafrost, depth of active layer and temperature of permafrost. The source for this information is 'Merzlotnye Landshafty Yakutii' (Permafrost Landscapes of Yakutia) (Fedorov et al., 1989) and its accompanying 'Merzlotno-landshaftnaya Karta Yakutskoi ASSR' (Permafrost Landscapes Map of the Yakut ASSR, scale 1 : 2,500,000) (Fedorov et al. eds., 1989). Fig.4.1 shows the location of the transects, the first of which runs from Mirnyy to Yakutsk; the second, [illegible] to a point [illegible] of [illegible] (on the [illegible] border).

[illegible] and colleagues representatives of the Institut Merzlotovedeniya [illegible] of [illegible]

Figure 4.17 Schematic map of ice wedge distribution in the former USSR (Sakha outlined) (a), and recent and relic ice wedges in the Sakha Republic (b). Source: Klimovsky & Murzin, 1993.



Key: (1) Yakutsk, (2) the settlement of Polyarnoye, (3) the settlement of Zelenyi Mys. Ice wedge distribution (%): (1) < 2; (2) 2–5; (3) 5–10; (4) 10–20; (5) 20–50; (6) > 50. Limits: (7) limit of permafrost zone; (8) limit of relic ice wedges; (9) limit of relic ice wedges in the Near-Baikal area; (10) limit of recent ice wedges; (11) line dividing continuous and discontinuous permafrost zones. (b) Recent (▾) and relic (.) ice wedges.

Figure 4.18 Ice wedge in northeastern Sakha. Note the person at the top for scale. Source: Klimovsky & Murzin, 1993.

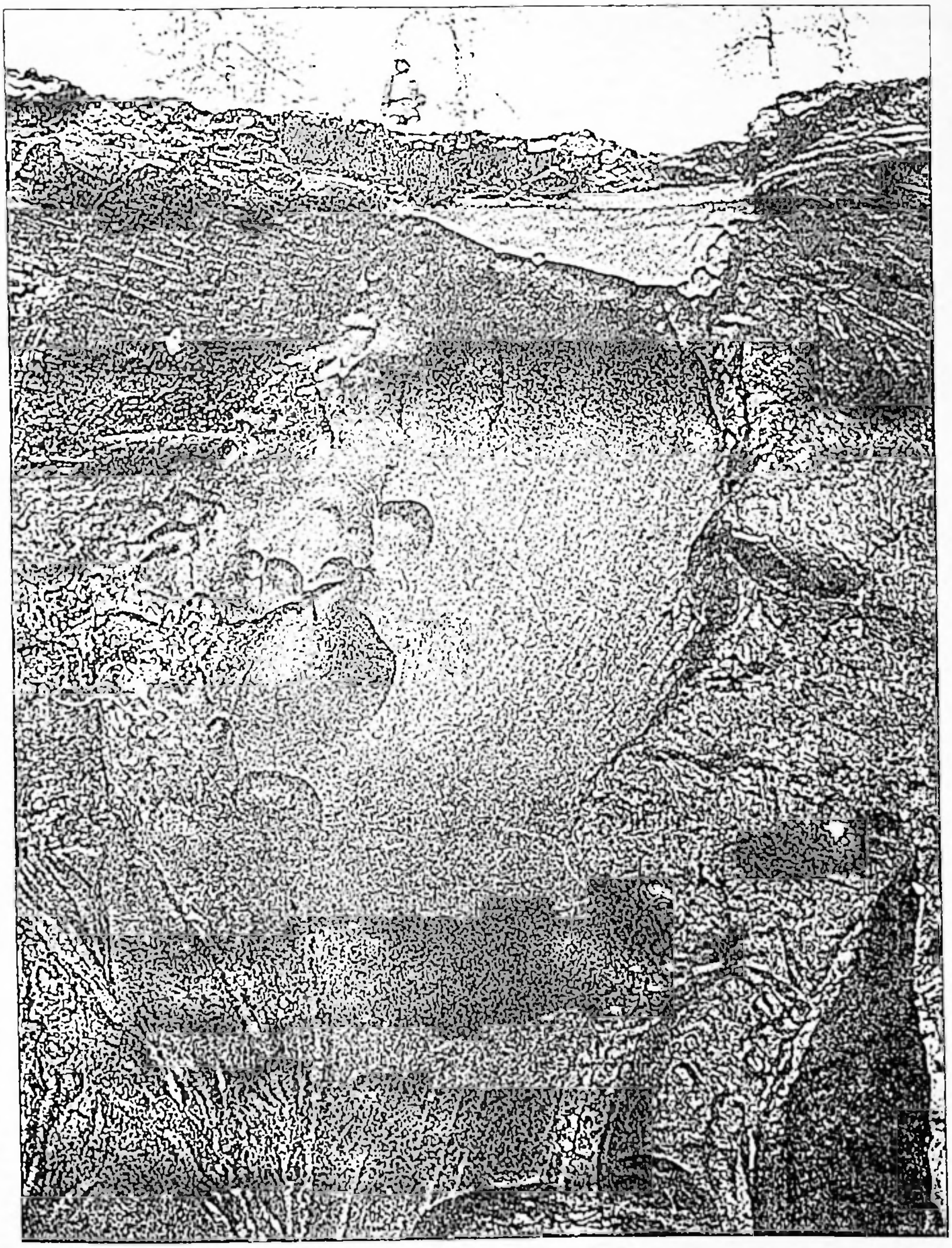


Figure 4.19 A cross-section of permafrost, showing depths of the permafrost table and the base of the seasonally fluctuating layer.

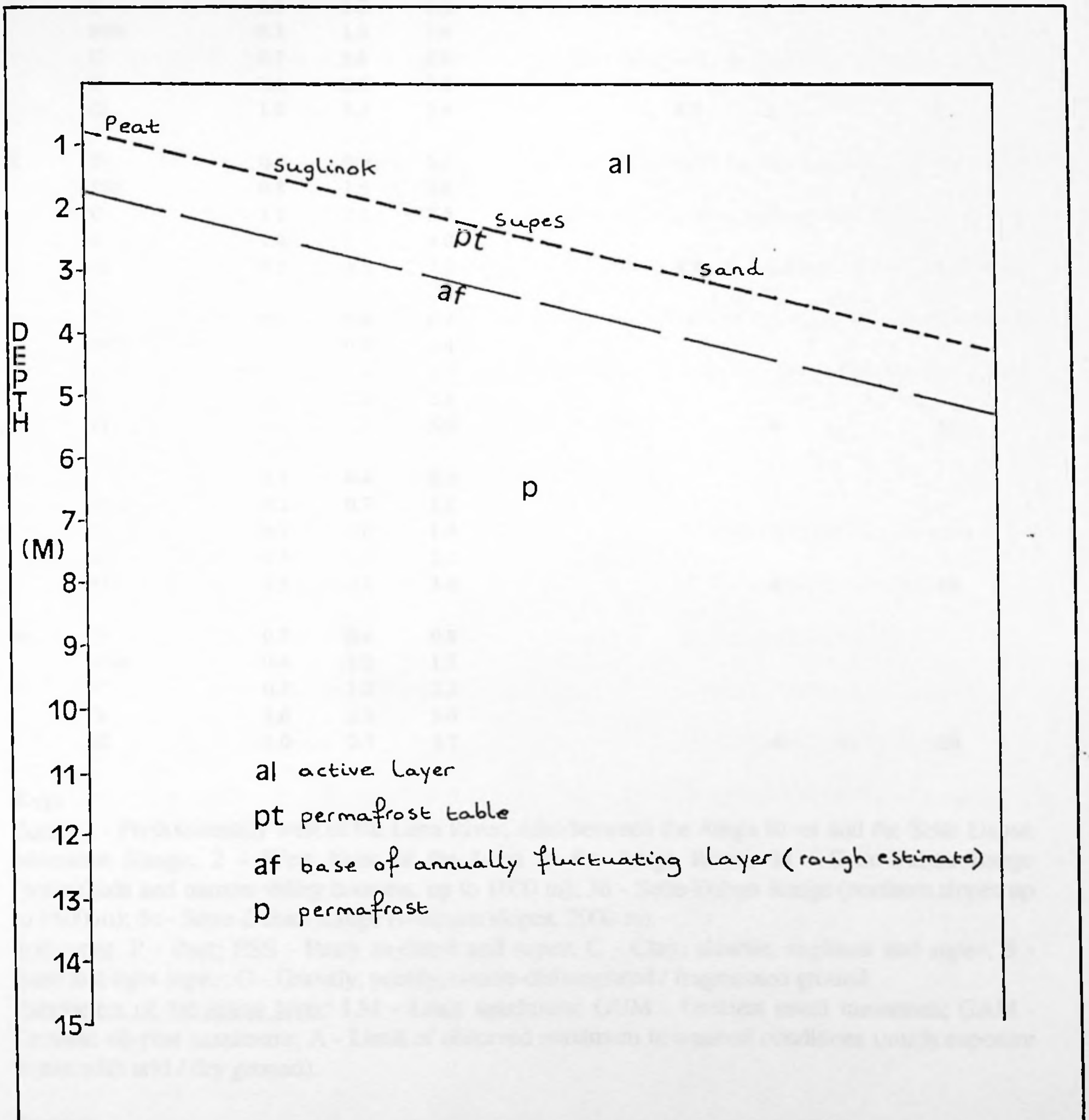


Figure 4.19 A cross-section of permafrost, showing depths of the permafrost table and the base of the seasonally fluctuating layer.

Table 4.2

Characteristics of the active layer and ground temperatures

Zone	Soil type	Greatest depth of seasonal thawing (m)			Lowest annual average ground temperature (°C)		
		LM	GUM	GAM	A	from	to
1	P	0.3	0.7	1.0			
	PSS	0.3	1.3	1.6			
	C	0.7	1.8	2.0			
	S	1.4	2.5	3.0			
	G	1.8	3.3	3.8	4.5	-2	-5
2	P	0.4	0.9	1.2			
	PSS	0.8	1.6	2.0			
	C	1.1	2.1	2.5			
	S	1.4	3.2	4.0			
	G	2.2	4.2	5.0	6.0	-1.5	-3
3a	P	0.1	0.4	0.7			
	PSS	0.2	0.9	1.4			
	C	0.4	1.4	1.7			
	S	0.6	2.0	2.4			
	G	0.6	2.3	3.0		-4	-10
3b	P	0.1	0.4	0.6			
	PSS	0.2	0.7	1.1			
	C	0.3	1.0	1.4			
	S	0.5	1.3	2.2			
	G	0.5	2.2	3.0		-4	-10
3c	P	0.2	0.6	0.8			
	PSS	0.4	1.2	1.7			
	C	0.7	1.7	2.3			
	S	1.0	2.5	3.0			
	G	1.0	2.7	3.7		-4	-10

Key:
Zones: 1 - Predominantly west of the Lena River. Also between the Amga River and the Sette-Daban Mountain Range; 2 - West bank of the Lena to the Amga River; 3a - Sette-Daban Range (watersheds and narrow valley bottoms, up to 1600 m); 3b - Sette-Daban Range (northern slopes up to 1500 m); 3c - Sette-Daban Range (southern slopes, 2000 m).
Soil types: P - Peat; PSS - Peaty *suglinok* and *supes*; C - Clay, aleurite, *suglinok* and *supes*; S - Sand and light *supes*; G - Gravely, pebbly, coarse-disintegrated / fragmented ground.
Parameters of the active layer: LM - Least maximum; GUM - Greatest usual maximum; GAM - Greatest all-year maximum; A - Limit of observed maximum in unusual conditions (much exposure to sun with arid / dry ground).

Source:
Adapted from Fyodorov *et al.*, 1989, p.24, Table II.2.

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Permafrost characteristics of the Mirnyy - Yakutsk transect.

Mirnyy, with a population of over 50,000, was chosen as the starting point since it is the centre of the Nepa-Botuobian oil and gas region. In the event of large-scale exports from this region, gas would be transmitted through pipelines originating in Mirnyy. Yakutsk lies almost halfway between Mirnyy and the Pacific coast and lies not far off a hypothetical line drawn between Mirnyy and the possible pipeline termination point of Okhotsk. Pipelines would almost certainly pass through the capital.

Fig.4.20 is a scale representation of the ca.800 km transect. The numbers on this map correspond to the numbers in bold print (e.g. **1)**) given below. The information contained under each number is that for each terrain zone (may include a combination of terrain types) along the transect and the various permafrost features characteristic of that particular terrain zone. Where translation proves ambiguous, the original Russian terminology has been included in square brackets[10]. Letters of the alphabet in fine print (e.g. a.) correspond to the following:

a. Relief.

b. Stratigraphic-genetic complexes.

c. Soils.

d. Main cryogenic textures (structures) and ground ice formations.

e. Volume of ice in ground (percentage).

f. Main periglacial processes.

g. Continuity of permafrost.

h. Depth of active layer.

i. Soil temperature at base of annually fluctuating layer[11].

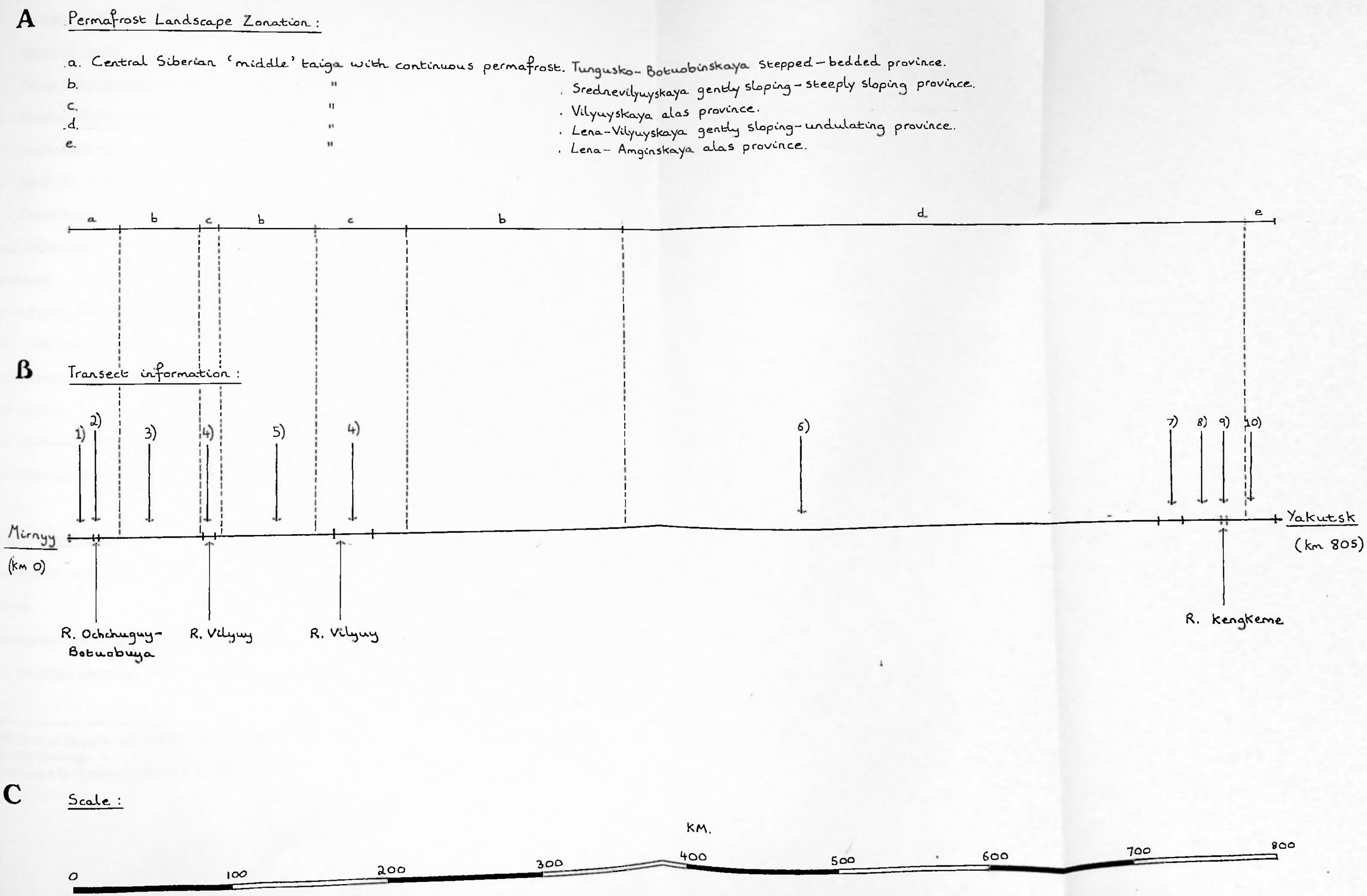
j. Vegetation (only predominant vegetation types given).

1) Slope (middle taiga):

a. Sloping river valley, ranging from steep to gentle, and plateau.

[10]NOTE: this does not include the Russian terms *suglinok* and *supes*.
[11]This is the layer beneath which ground temperature is constant on an annual basis. It should not be confused with the Permafrost Table, the base of the active layer, which tends to be shallower. See Fig.4.19.

Figure 4.20 The Mirnyy to Yakutsk transect.



b. Complex sloping sediments, original earth materials [*korennyye porody*].

c. Typical frozen northern and middle taiga (peaty and carbonaceous), rich in detritus, washed away [*smytyye*].

d. Stratified, ice lenses (*suglinok* and *supes*).

Massive[12] (sand).

Crusty, basal, goltsy ice[13] (coarse fragments with aggregate).

Fissures (original earth materials).

e. *Suglinok* and *supes* : 30 - 60 %.

Sand : 30 - 50 %.

Coarse fragments with aggregate : 30 - 50 %.

f. Creep, solifluction, frost shattering, rock glaciers.

g. Continuous.

h. 0.5 - 4.3 m (predominantly 1.0 - 2.5 m).

i. -0.5 - -7.0°C (predominantly -1.0 - -3.0°C).

j. Larch (*Larix dahurica*) woods with occasional pines with bearberry (*Arctostaphylos uva-ursi*) and lichens (*Cetraria cucullata, Cladina arbuscula*); and larch woods with Manchurian alder thickets (*Alnus fruticosa*), shrubs (*Lednum palustre, Vaccinium vitis-idaea*) and mosses and lichens (*Hylocomium splendens, Pleurozium schreberi, Cetraria cucullata, Cladina arbuscula*).

2) Shallow valley (middle taiga):

a. Base of small river valley.

b. Alluvial.

c. Frozen peaty- / peat-bogs, boggy meadow, turfy-woody and alluvial (stratified).

d. Stratified, ice lenses, reticular[14] (peat, *suglinok* and *supes*).

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[12]In this context, 'massive' refers to sand that is frozen in its entirity with no ice layers caused by ice segregation (heaving).

[13]See definition in Glossary of Russian terms and abbreviations.

Massive (sand).

Minor systems of polygonal wedge ice.

e. Peat : 65 - 85 % (including wedge ice : 70 - 90 %).

Suglinok and *supes* : 35 - 65 % (including wedge ice : 40 - 75 %).

Sand : 30 - 45 %.

f. Frost shattering, thermokarst, heaving.

g. Continuous with sub-river bed taliks.

h. 0.4 - 3.2 m (predominantly 0.8 - 1.5 m).

i. 0 - -5.0°C (-1.5 - -4.0°C).

j. Mixed spruce-larch woods with shrubs (*Lednum palustre, Vaccinium vitis-idaea*) and byrophytes (*Aulaconnium turgidum, Pleurozium schreberi, Ptilidium ciliare*), scrub birch (*Betula fruticosa*), reed grass (*Calamagrostis langsdorffii*), sedge (*Carex juncella*) meadows and sphagnum (*Sphagnum balticum, Sphagnum fimbriatum*).

3) Terrace and slope (middle taiga):

Note: slope characteristics are the same as those outlined in **1)** and are therefore omitted. The information here is for "terrace" only.

a. Plateau area of flat plain in watershed zone between rivers.

b. Eluvial, eluvial-deluvial, original earth materials [*Korennyye porody*].

c. Typical frozen taiga (some northern taiga), detritus, with some podzol and carbonaceous turf.

d. Stratified, ice lenses (*suglinok* and *supes*).

Massive (sand).

Crusty (coarse fragments with aggregate).

Fissures (original earth materials).

e. Suglinok and supes : 35 - 55 %

[14]'Reticular' means that there are both horizontal and vertical ice wedges within the soil. In cross section, the soil would have a net-like appearance.

Sand : 30 - 50 %.

Coarse fragments with aggregate : 25 - 40 %.

f. Frost shattering.

g. Continuous.

h. 0.8 - 4.0 m (predominantly 1.3 - 2.0 m).

i. -0.5 - -3°C (predominantly -1.0 - -2.5°C).

j. Larch woods with occasional pine with bearberry (*Arctostaphylos uva-ursi*) with lichen (*Cetraria cucullata, Cladina arbuscula*), shrubs such as Manchurian alder (*Alnus fruticosa*) and dog rose (*Rosa acicularis*); and shrubby (*Vaccinium uliginosum, Ledum palustre, Vaccinium vitis-idaea*) larch woods with lichen and mosses (*Aulaconnium turgidum, Cladina arbuscula*) and alder undergrowth. Some spruce (*Picea obovata*).

4) Low terrace (contemporaneous with a large river valley) (middle taiga):

a. Floodlands and low above-floodplain terraces of the Vilyuy River valley.

b. Alluvial.

c. Frozen turfy-woody, turfy meadowy, meadowy-marshy peaty- and peat-bogs, alluvial (stratified) and podzolized taiga.

d. Stratified, ice lenses, reticular (peat, *suglinok* and *supes*).

Massive (sand).

Minor systems of polygonal wedge ice.

e. Peat : 65 - 80 % (including wedge ice : 70 - 85 %).

Suglinok and *supes* : 40 - 75 % (40 - 75 %).

Sand : 30 -50 %.

f. Frost shattering, thermokarst, heaving.

g. Continuous with sub-river bed taliks.

h. 0.5 - 3.5 m (predominantly 1.3 - 2.0 m).

i. 0 - -5°C (predominantly -1.0 - -3.0°C).

j. Larch woods with occasional spruce shrubbery (*Lednum palustre, Vaccinium vitis-idaea*) and grasses (*Calamagrostis langsdorffii, Poa pratensis, Equisetum pratense*) with sedge (*Carex juncella*) meadows, and mosses (*Pleurozium schreberi, Aulacomnium turgidum*).

5) Terrace, slope and inter-alas (middle taiga):

Note: terrace and slope characteristics are the same as those outlined in **1)** and **3)** and are therefore omitted. The information here is for "inter-alas" only.

a. Flat plain surface of the fragmented River Vilyuy high terrace.

b. Lacustrine-alluvial, alluvial in places.

c. Typical frozen light-coloured taiga, solodized.

d. Stratified, ice lenses, reticular, zonal (*suglinok* and *supes*).

Massive (sand).

Major systems of polygonal wedge ice.

e. *Suglinok* and *supes* : 35 - 65 % (including wedge ice : 45 - 85 %).

Sand : 30 - 45 % (including wedge ice : 40 - 70 %).

f. Thermokarst.

g. Continuous.

h. 0.8 - 2.4 m (predominantly 1.2 - 1.7 m).

i. -1.0 - -6.0°C (predominantly -2.0 - -4.0°C).

j. Shrubby (*Viccinium vitis-idaea*) larch woods with heterogeneous grasses (*Pyrola incarnata, Thalictrum minum*), occasional pine in places, often with birch woods.

6) Terrace and slope (middle taiga):

Note: This is a very large area, spanning two middle taiga provinces. In the first province, all characteristics are the same as those described in **3)** and are therefore omitted. In the second province, all characteristics are similar except a., c. and j. and so these will be described below.

Terrace:

a. Plateau area in watershed zone between rivers.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

c. Typical frozen taiga and podzolized.

j. Shrubby (*Vaccinium vitis-idaea, Ledum palustre, Vaccinium uliginosum*) larch woods with mosses (*Hylocomium splendens, Pleurozium schreberi*), often with occasional pine and *Limnas stelleri*, and occasional kinnikinic (*Arctostaphylos uva-ursi*) woods, with lichens (*Cladina stellaris, Cetraria cucullata*).

Slope:

a. A combination of: steep denudation slopes and river valley; river valley slopes and plateau of average steepness; gently sloping river valley slopes and plateau.

c. Podzolizing and turfy-carbonaceous podzolizing frozen taiga, rich in detritus, washed away (*smytyye*). Occasional gleying and carbonaceous humus.

j. A combination of: pine woods with bearberry (*Arctostaphylos uva-ursi*), lichens (*Cladina stellaris, Cetraria cucullata*) with *Limnas stelleri*; larch woods, often with occasional pine, shrubs (*Vaccinium vitis-idaea, Lednum palustre*) with *Limnas stelleri* and mosses (*Hyloconium splendens, Pleurozium schreberi*); shrubby larch woods, mosses (*Aulaconium turgidum, Pleurozium schreberi, Hyloconium splendens*), with occasional pine in places and undergrowth of Manchurian alder (*Alnus fruticosa*) and scrub birch (*Betula fruticosa*), and grassy (*Calamagrostis langsdorffii, Poa pratensis, Thalictrum minus*) larch woods, with red whortleberry (*Vaccinium vitis-idaea*).

7) Watershed zone with poor drainage (watershed-*mari*[15] zone of middle taiga):

a. Inter-plateau area of poorly drained watershed.

b. Biogenic, eluvial.

c. Frozen peaty- and peat-bogs in combination with taiga in poor condition (humus-gley).

d. Stratified, ice lenses, reticular (peat, *suglinok* and *supes*).

Massive (sand).

Minor systems of polygonal wedge ice.

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[15]See Glossary of Russian terms and abbreviations for explanation of *mari*.

e. Peat : 65 - 85 % (including wedge ice : 70 - 90 %).

Suglinok and supes : 45 - 65 %.

Sand : 30 - 45 %.

f. Thermokarst, heaving.

g. Continuous with sub-lake taliks.

h. 0.3 - 1.2 m (predominantly 0.4 - 0.8 m).

i. -0.4 - -4.0°C.

j. Shrubby bogs (mainly bog myrtle (*Chamaedaphne calyculata*)), with sphagnum (*Sphagnum balticum, Sphagnum angustifolium*), and sedge (*Carex juncella*), scrub birch (*Betula fruticosa*) in combination with larch and shrubs (*Lednum palustre*) and with lichen-sphagnum.

8) Slope (middle taiga):

Note: All characteristics as for **1)** except c. and j.

c. Podzolized frozen taiga and turfy-carbonaceous podzolized, rich in detritus, washed away [*smytyye*], humus-carbonaceous.

j. Pine woods with bearberry (*Arctostaphylos uva-ursi*), lichens (*Cladina stelleris, Cetraria cucullata*) with *Limnas stelleri*; larch woods, often with occasional pine, shrubs (*Vaccinium vitis-idaea, Lednum palustre*) with *Limnas stelleri* and shrubs (*Viccinium uliginosum*) with mosses (*Hylocomium splendens, Pleurozium schreberi*). On gentle slopes: areas of pine often with undergrowth of Manchurian alder (*Alnus fruticosa*) and scrub birch (*Betula fruticosa*), and larch woods with grasses (*Calamagrostis langsdorffii, Poa pratensis, Thalictrum minus*).

9) Shallow valley (middle taiga):

Note: All characteristics as for **2)** except j.

j. Combination of larch woods with occasional spruce (*Picea obovata*), shrubs (*Lednum palustre, Vaccinium vitis-idaea*) with mosses (*Aulaconnium turgidum*), scrub birch (*Betula fruticosa*),

grasses (*Calamagrostis langsdorffii, Bromopsis pumpelliana*) and sedge (*Carex juncella*) meadows.

10) Slope and inter-alas (middle taiga):

Note: slope and inter-alas characteristics as for **5**) except for a., c. and j. in both cases.

Slope:

a. Combination of: gently sloping river valley and plateau; and steeply sloping river valley.

c. Typical frozen taiga and podzolized, or turfy poor-podzol with podzol in places. Occasional turfy-carbonaceous detritus, washed away [*smytyye*].

j. Larch woods, often with occasional pines, *Limnas stelleri*, with red whortleberry (*Vaccinium vitis-idaea*) with areas of grasses (*Thalictrum minus*), mixed larch-pine woods in places with bearberry (*Arctostaphylos uva-ursi*), with lichens (*Cladina stellaris, Cetraria cucullata*). On steep slopes; steppe meadows with sedge (*Carex duriuscula*) and anemone (*Pulsatilla flavescens*).

Inter-alas:

a. Flat tracts of lacustrine-alluvial plain and high terraces of Lena River.

c. Pale solodized frozen taiga, carbonaceous, and swampy.

j. Larch woods with *Limnas stelleri*, red whortleberry (*Vaccinium vitis-idaea*) with areas of grasses (*Thalictrum minus*), and larch woods with occasional pine and *Limnas stelleri*.

Permafrost characteristics of the Yakutsk to Solnechnyy transect.

This transect follows a straight line drawn between Yakutsk and the coastal settlement of Okhotsk. The following two considerations led to Okhotsk being chosen as the eastern point. First, it is some 430 km closer to Yakutsk than Magadan. Second, given the availability of information and data, it is possible to provide a more comprehensive review of the permafrost characteristics of the Yakutsk to Okhotsk transect than on those of the Yakutsk to Magadan transect. Conditions would not be markedly different for the two transects in any case. The transect itself goes as far as a point on the

Sakha / Khabarovsk border (northeast of Solnechnyy and 325 km from Okhotsk). The permafrost characteristics on this transect are representative of those encountered in the wider area between Yakutsk and the border.

Fig.4.21 is a scale representation of the ca.475 km Yakutsk to Solnechnyy transect. All the criteria for the Mirnyy to Yakutsk transect (e.g. numbers in bold print and letters in fine print) also apply here. The Russian soil science terms *solonets* and *solonchak*[16] are retained.

1) Low terrace (contemporaneous with a large river valley) (middle taiga):

a. Floodlands and low above-floodplain terraces.

b. Alluvial.

c. Frozen floodplain turfy-woody (coniferous forest podzol in places) in combination with black earth *solonets*, black earth meadowy *solonchak-solonets* with *solonchak* and *solonets*, turfy-meadow, meadow and turfy bog, also alluvial (stratified).

d. Stratified, ice lenses, reticular (peat, *suglinok* and *supes*).

Massive (sand).

Minor systems of polygonal wedge ice.

e. Peat : 65 - 80 % (including wedge ice : 70 - 85 %).

Suglinok and *supes* : 35 - 65 % (including wedge ice : 40 - 75 %).

Sand : 30 - 50 %.

f. Frost shattering, thermokarst, heaving.

g. Continuous with sub-river bed taliks.

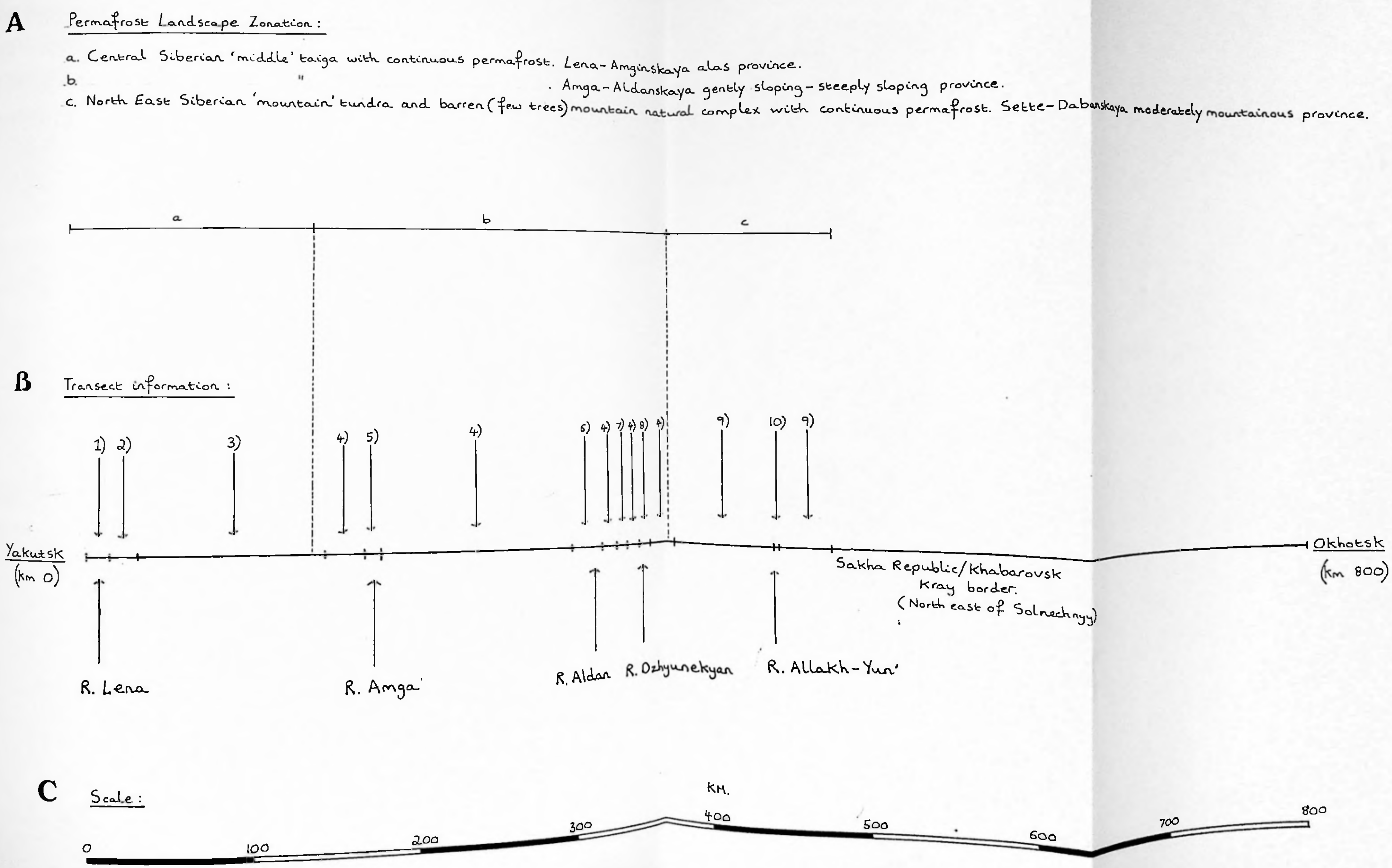
h. 0.5 - 3.5 m (predominantly 1.3 - 2.0 m).

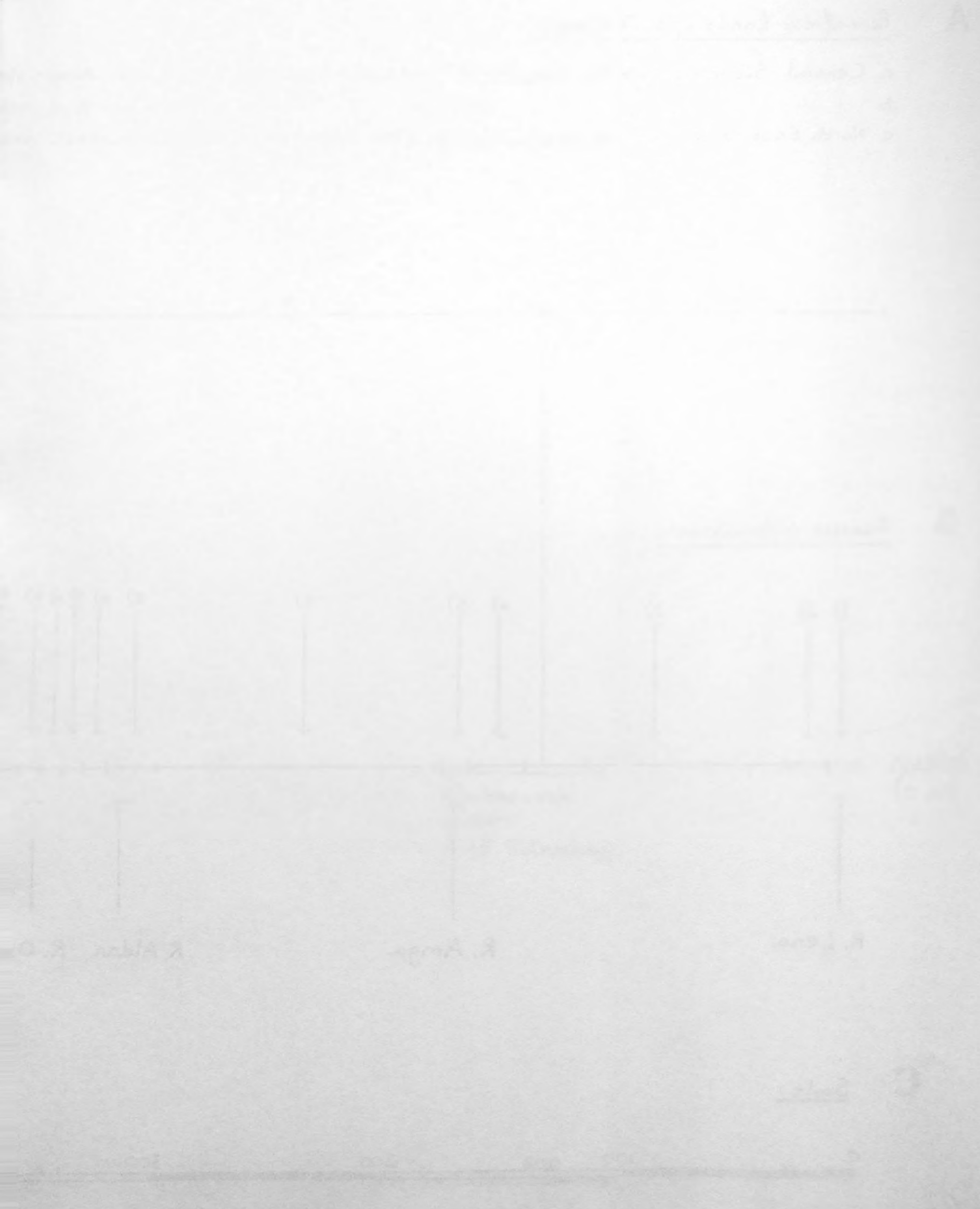
i. 0 - -5.0°C (predominantly -1.0 - -3.0°C).

j. larch woods with red whortleberry (*Vaccinium vitis-idaea*) and grasses, e.g. reed grass (*Calamagrostis langsdorffii*) meadow grass (*Poa pratensis*) and *Equisetum pratense*, larch woods

[16]The terms *solonets* and *solonchak* are recognized in the English language since they cannot be translated into single words. For an explanation see the Glossary of Russian terms and abbreviations.

Figure 4.21 The Yakutsk to Solnechnyy transect.





with pine shrubbery and red whortleberry, *Vaccinium uliginosum*, mixed spruce-larch woods with mosses (*Aulacomnium turgidum, Tomenthypnum nitens*) occasionally with meadow-steppe sedge (*Carex duriuscula*), grasses (*Hordeum brevisubulatum, Galium verum, Calamagrostis langsdorffii*), sedge (*Carex juncella*) meadows and willow (*Salix viminalis*).

2) Sandy ridges of a terrace of average height (middle taiga):

a. Sandy and gravely areas on a middling to high terrace of a large river (Lena).

b. Alluvial with aeolian fragments.

c. Frozen turfy poor-podzol [*slabopodzolistyye*].

d. Massive, ice lenses (sand).

Sparse layers of ice.

e. Sand : 30 - 45 %.

f. Frost shattering, thermosuffosion.

g. Continuous.

h. 1.0 - 5.0 m (predominantly 2.0 - 3.0 m).

i. 0 - -2.0°C (predominantly -0.2 - -1.5°C).

j. Pine and mixed larch-pine woods with *Limnas stelleri* and bearberry (*Arctostaphylos uva-ursi*) occasional red whortleberry (*Vaccinium vitis-idaea*) in places.

3) Alas (watershed-*mari* zone of middle taiga) and inter-alas (middle taiga):

Alas:

a. Bottom of thermokarst depressions.

b. Thermokarst.

c. Combination of alas soils: meadowy-black earth, black earthy-meadow, turfy-meadowy, meadowy-boggy *solonchak* / *solonets*, peaty- and peat-bogs.

d. Stratified, ice lenses, reticular, zonal, basal (peat, *suglinok* and *supes*).

Massive (sand).

Minor systems of polygonal wedge ice.

e. Peat : 65 - 90 % (including wedge ice : 70 - 95 %).

Suglinok and *supes* : 35 - 60 % (including wedge ice : 45 - 70 %).

Sand : 30 - 45 %.

f. Frost shattering, heaving, thermokarst.

g. Continuous with sub-lake taliks.

h. 0.5 - 3.0 m (predominantly 1.2 - 1.8).

i. 0 - -5.0°C (predominantly -0.2 - -2.0°C).

j. Alas meadows with sedge (*Carex juncella*) and reed grass (*Calamagrostis langsdorffii*), variety of grasses, including gramineous varieties (*Alopecurus arundinaceus, Potentilla anserina, Hordeum brevisubulatum, Galium verum*) also *Puccinellia tenuiflora, Saussurea amara*, steppe sedge (*Carex duriuscula, Festuca kolymensis, Artemisia commutata*).

Inter-alas:

a. Low tracts of a lacustrine-alluvial plain and high terraces of a large river (Lena).

b. Lacustrine-alluvial, alluvial in places.

c. Frozen pale-yellow podzolized taiga, carbonaceous and boggy.

d. Stratified, ice lenses, reticular, zonal (*suglinok* and *supes*).

Massive (sand).

Major systems of polygonal wedge ice.

e. *Suglinok* and *supes* : 35 - 65 % (including wedge ice : 45 - 85 %).

Sand : 30 - 40 % (including wedge ice : 40 - 70 %).

f. Thermokarst.

g. Continuous.

h. 0.8 - 2.4 m (predominantly 1.2 - 1.7 m).

i. -1.0 - -6.0°C (predominantly -2.0 - -4.0°C).

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

j. Larch woods with *Limnas stelleri* and red whortleberry (*Vaccinium vitis-idaea*) with areas of grasses (*Thalictrum minus*); larch woods with scattered pine, *Limnas stelleri* and red whortleberry.

4) Terrace and slope (middle taiga):

Terrace:

a. Watershed zone plateau area between rivers.

b. Eluvial, eluvial-deluvial, original earth material [*korennyye porody*].

c. Typical frozen taiga and podzolized or frozen turfy-carbonaceous and podzolized turfy-carbonaceous.

d. Stratified, ice lenses (*suglinok* and *supes*).
Massive (sand).
Crusty (coarse fragments with aggregate).
Fissures (original earth material).

e. *Suglinok* and *supes* : 35 - 55 %.
Sand : 30 - 50 %.
Coarse fragments with aggregate : 25 - 45 %.

f. Frost shattering.

g. Continuous.

h. 0.8 - 4.0 m (predominantly 1.3 - 2.0 m).

i. -0.5 - -3.0°C (predominantly -1.0 - -2.5°C).

j. Larch woods, often with occasional pine, shrubs (*Vaccinium vitis-idaea, Vaccinium uliginosum, Lednum palustre*) with Limnas stelleri, mosses in places (*Aulacomnium turgidum, Pleurozium schreberi*) occasionally with mixed larch-pine woods with shrubs *Vaccinium vitis-idaea, Arctostaphylos uva-ursi*) with *Limnas stelleri*.

Slope:

a. Steep slopes of a river valley, moderately steep slopes in valley zone, gentle slopes and plateau.

b. Complex sloping sediments, original earth material [*korennyye porody*].

c. Typical frozen podzolized taiga, turfy-carbonaceous, rich in detritus, washed away [*smytyye*], often gleying, humus-carbonaceous.

d. Stratified, ice lenses (*suglinok* and *supes*).

Massive (sand).

Crusty, basal, goltsy ice (coarse fragments with aggregate).

Fissures (original earth materials).

e. *Suglinok* and *supes* : 30 - 65 %.

Sand : 30 - 50 %.

Coarse fragments with aggregate : 30 - 45 %.

f. Creep, solifluction, frost shattering, rock glaciers.

g. Continuous.

h. 0.5 - 4.3 m (predominantly 1.0 - 2.5 m).

i. -0.5 - -7.0°C (predominantly -1.0 - -3.0°C).

j. Steep slopes : pine and mixed larch-pine woods with shrubs (*Arctostaphylos uva-ursi, Vaccinium vitis-idaea*) with *Limnas stelleri*, with sparser areas of lichen (*Cladina stelleris, Cetraria cucullata*); moderate slopes : Larch woods, often with occasional pine, shrubs (*Vaccinium vitis-idaea, Vaccinium Uliginosum, Lednum palustre*) with *Limnas stelleri* and mosses (*Hyloconium splendens, Pleurozium schreberi*), with undergrowth of scrub birch (*Betula fruticosa*) and Manchurian alder (*Alnus fruticosa*) in places; gentle slopes : similar.

5) Low terrace (contemporaneous with a large river) (middle taiga):

Note: All characteristics as for **1**) except j.

j. *Hordeum brevisubulatum* and reed grass (*Calamagrostis langsdorffii*) meadows in combination with larch grasses (*Poa pratensis, Equisetum pratense*) with mosses (*Aulaconnium turgidum, Tomenthypnum nitens*).

6) Low terrace (contemporaneous with a large river) (middle taiga):

Note: All characteristics as for 1) except j.

j. Larch woods with pine and shrubs (*Vaccinium vitis-idaea, Vaccinium uliginosum*) with mosses (*Aulacomnium turgidum, Tomenthypnum nitens*) in combination with reed grass (*Calamagrostis langsdorffii*) and sedge (*Carex juncella*) meadows.

7) Mountain slope (Mountainous with few trees):

a. Steep and moderately steep denudation slopes.

b. Complex sloping sediment, original earth material [*korennyye porody*].

c. Steep slopes : residual-carbonaceous mountain tundra, rich in detritus, washed away [*smytyye*]. Moderately steep slopes : .... taiga and mountainous turfy-carbonaceous washed away detritus.

d. Stratified, ice lenses, crusty (detritus *suglinok*).

Massive (detritus sand).

Basal, reticular, goltsy ice (coarse fragments with aggregate).

Fissures (original earth materials).

e. Detritus *suglinok* : 30 - 70 %.

Detritus sand : 25 - 45 %.

Coarse fragments with aggregate : 25 - 65 %.

f. Cryogenic weathering, rock glaciers, solifluction, creep.

g. Continuous.

h. 0.3 - 3.2 m (predominantly 0.6 - 1.8 m).

i. -2.0 - -9.0°C (predominantly -3.0 - -6.0°C).

j. Steep slopes : very sparse shrub thickets (*Vaccinium vitis-idaea, Empetrum nigrum*) with lichen (*Cladina stelleris, Cetraria nivalis*) and dead ground cover-crops [*mertvopokrovnyye*]. Moderately steep slopes : sparse larch and shrubs (*Vicciniurn vitis-idaea, Vaccinium uliginosum, Empetrum nigrum, Cassiope ericoides*) with mixed moss-lichen (*Cladina arbuscula, Cladina stelleris,*

Cetraria islandica, Pleurozium schreberi) with shrubs (*Betula divaricata, Betula exilis, Pinus pumila*).

8) Shallow valley (middle taiga):

a. Valley bottom of a small river.

b. Alluvial.

c. Frozen floodplain turfy-woody, meadowy-peaty and peaty-boggy, alluvial (stratified).

d. Stratified, ice lenses, reticular (peat, *suglinok* and *supes*).

Massive (sand).

Systems of minor polygonal wedge ice.

e. Peat : 65 - 85 % (including wedge ice : 70 - 90 %).

Suglinok and *supes* : 35 - 65 % (including wedge ice : 45 - 75 %).

Sand : 30 - 45 %.

f. Frost shattering, thermokarst, heaving.

g. Continuous with sub-river bed taliks.

h. 0.4 - 3.2 m (predominantly 0.8 - 1.5 m).

i. 0 - -5.0°C (predominantly -1.5 - -4.0°C).

j. Larch woods with shrubs (*Vaccinium vitis-idaea, Vaccinium uliginosum, Lednum palustre*), mosses (*Aulaconnium turgidum, Tomenthypnum nitens*) with areas of *Chozeniyevykh* and poplar woods in places.

9) Mountain slope (mountainous with few trees; sub-goltsy with shrub thickets):

a. Steep slopes and slopes of moderate steepness of medium height and low mountain ranges; piedmont slopes of a mountain range.

b. Complex sloping sediment, original earth materials [*korennyye porody*].

c. Rock debris, mountain goltsy, graded tundra podzol, mountain tundra, residual-carbonaceous, rich in detritus, washed away [*smytyye*]. Piedmont : turfy carbonaceous.

d. Stratified, ice lenses, crusty (detritus *suglinok*).

Massive (detritus sand).

Basal, reticular, goltsy ice (coarse fragments with aggregate).

Fissures (original earth materials).

e. Detritus *suglinok* : 30 - 70 %.

Detritus sand : 25 - 45 %.

Coarse fragments with aggregate : 25 - 65 %.

f. Weathering rock glaciers, solifluction and creep.

g. Continuous.

h. Mountainous with few trees : 0.3 - 3.2 m (predominantly 0.6 - 1.8 m).

Sub-goltsy with shrub thickets : 0.3 - 2.5 m (predominantly 1.2 - 1.8 m).

i. Mountainous with few trees : -2.0 - -9.0°C (predominantly -3.0 - -6.0°C).

Sub-goltsy with few trees : -3.0 - -9.0°C.

j. Arid mountain lichen (*Rhizocarpon geographicum, Haematomma ventosum, Umbilicaria*), rocky, mountianous tundra lichen (*Alectoria ochroleuca, Coelocaulon divergens*) and shrubs (*Dryas punctata, Cassipoe tetragona*), shrub thickets (*Vaccinium vitis-idaea, Empetrum nigrum*), lichens (*Cladina stelleris, Cetraria islandica, Cetraria nivalis, Pleurozium schreberi*) and dead ground cover crops [*mertvopokrovnyye*], very sparse larch with occasional birch (*Betula exilis, Betula divaricata*). Piedmont : also lichen and mixed moss-lichen (*Aulaconmium turgidum, Cetraria cucullata, Cladina arbuscula*).

10) Mountain-valley (mountain taiga):

a. Valley bottom of a mountain river.

b. Alluvial.

c. frozen floodplain turfy-woody, meadowy-, turfy- and turfy-marshy, alluvial (stratified).

d. Stratified, ice lenses, reticular (peat, *suglinok* and *supes*).

Massive, crusty (sandy-gravel).

Minor polygonal wedge ice in places.

e. Peat : 65 - 90 % (including wedge ice : 65 - 95 %).

Suglinok and *supes* : 45 - 65 % (including wedge ice : 50 - 75 %).

Sandy-gravel : 25 - 45 %.

f. Frost shattering, thermokarst, heaving.

g. Continuous with sub-river bed taliks.

h. 0.2 - 2.0 m (predominantly 0.6 - 1.2 m).

i. -1.0 - -7.5°C (predominantly -2.5 - -5.0°C).

j. Sparse larch and birch (*Betula exilis, Betula divaricata*) shrubs (*Lednum palustre, Vaccinium uliginosum*) with mosses (*Aulaconmium turgidum*) and sphagnum (*Sphagnum balticum*) with areas of *chozeniyevykh* and poplar woods, and bog.

Chapter 5

Strategies for Pipeline Operation and Construction

5.1 INTRODUCTION

Having outlined the environmental characteristics of transects between Mirnyy and Yakutsk, and Yakutsk and the Sakha / Khabarovsk border, we are now in a position to consider some suggestions regarding the operation and construction of a gas pipeline running from the Nepa-Botuobian region to the Sea of Okhotsk coast. First, it would be useful to draw from chapter 4 the most significant environmental characteristics of central Sakha, from the point of view of gas pipeline construction and operation, and to compare these briefly to characteristics found in southern Sakha and further south[1].

The crucial difference between the route suggested in this thesis and the one proposed by the Koreans and Japanese relates to the latitudes through which the pipelines would run. In our scenario, the pipeline is oriented west - east. Thus, latitudinal variation along the pipeline right-of-way would vary minimally. The reverse is evident for the Japanese / Korean proposal, which lays down plans for a pipeline right-of-way oriented north - south. Clearly, latitudinal variation is in this case maximized. The implications of the latter scenario are not favourable for gas pipeline, or for that matter oil pipeline, operation and construction for the following reasons.

Broadly speaking, as latitudinal variation increases, environmental uniformity decreases. An outstanding example of this can be seen with respect to permafrost continuity. Along the two transects described in chapter 4, permafrost is continuous. Admittedly, the pipeline would have to be laid through a relatively small zone of discontinuous permafrost once within maritime Khabarovsk Kray. Nevertheless, this is tiny (less than 100 km) in comparison to the vast zone of discontinuous

[1]Space precludes a separate examination of environmental characteristics in southern Sakha and the regions of the Pacific south east.

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and sporadic permafrost through which a north - south oriented pipeline would pass[2]. A buried pipeline passing through such diverse permafrost conditions would face a range of problems. If chilled, the pipeline would be subject to serious frost heaving in the discontinuous and sporadic zones. If warm, the pipeline would experience thaw settlement where the pipeline melted permafrost. There are other notable examples. In the west - east scenario variations in soil type are small in comparison to those for the north - south scenario. As shall be seen, significant soil type variations, coupled with permafrost conditions, are a recipe for disaster for a gas pipeline. A pipeline following the north - south route would be at risk from frequent seismic activity in the south Sakha and western Amur regions. Seismic activity is not as prevalent in the regions through which a west - east pipeline might pass. Both routes would transit mountainous relief, but altitudinal variation and extent of mountainous relief is less pronounced for the west - east route. There is significantly less chance of disturbance to reindeer breeding and associated migratory movements in central Sakha than in south Sakha, where there are large domesticated reindeer populations in mountainous areas.

Generally, it would appear that the north - south route has very few environmental advantages in its favour. In addition to this is the following major drawback. A north - south pipeline, as envisaged by the Japanese and Koreans, would be at least 5000 km long (Sakha Republic direct to South Korea and Japan) compared to ca.1760 km long between Mirnyy and Okhotsk. A longer pipeline will inevitably encounter a far wider range of obstacles along its right-of-way and would be far more susceptible to harmful interactions with the environment than a pipeline three times shorter. A pipeline of this length is not economically desirable either. Of paramount importance is that a pipeline is as short as possible, even if it means additional mileage for other modes being used on the same route (in this case LNG tankers) (Hotchkiss, 1994). This lowers the total cost of the construction phase significantly and thus the overall cost once pipeline transmission and tanker operations get under way. This strategy is central to a current BP feasibility study which

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[2]It has been noted recently that the terms 'discontinuous' and 'continuous' are misleading when used in the context of permafrost (Williams, 1994). This is because it is impossible to lay down boundaries between these two zones. There is no definite point at which permafrost stops being continuous and becomes discontinuous. Currently there are no replacements for these terms and so they have been retained.

[illegible]

is investigating ways of exporting gas from Prudhoe Bay, now that its oil reserves have been depleted. Instead of laying a gas pipeline to Alaska's south coast alongside the Trans-Alaska oil pipeline, BP proposes to build a shorter pipeline to Alaska's northwest coast (see Fig.5.1) from where ice-strengthened tankers would ship LNG to markets (Holleyoak, 1994).

There are significant advantages in using a combination of pipeline and LNG tanker modes as is illustrated by the case in question here. Although the Japanese / Korean plan foresees gas transmission from source to markets in pipelines alone, thus eliminating the need for costly gas liquefaction plants and LNG tankers, it suffers from an inability to adapt to future fluctuations in gas demand. The absence of a tanker stage means that should demand in Korea and Japan diminish or, more likely, demand elsewhere increase, the gas cannot be rerouted. Flexibility, in the form of tankers able to supply any number of markets and to change routes, is essential in view of highly fickle global energy demands. The central Sakha / tanker route would also avoid trouble spots such as North Korea through which the Korean and Japanese pipelines would have to pass. Political instability has made LNG tanker usage more attractive and reliable than single-mode pipeline options (Pezeshki & Fesharaki, 1994, p.6).

5.2 THE PIPELINE RIGHT-OF-WAY

It is important to bear in mind that the aim here is not to pin-point an exact route for the pipeline or to propose the implementation of specific measures for its construction and operation. In view of the still insufficient level of knowledge about large-diameter gas pipeline construction and operation in a permafrost environment, this would be unrealistic. Such decisions can only be made after months, if not years of study involving far more detailed research and numerous field trips to the pipeline right-of-way. The conclusions presented here should be regarded as suggestions.

Given these constraints, the following route could be used. There is little doubt that gas tapped from the fields of the Nepa-Botuobian fields would be fed into one or more large-diameter pipelines originating in Mirnyy, the regional centre. From here, one can only speculate on possible

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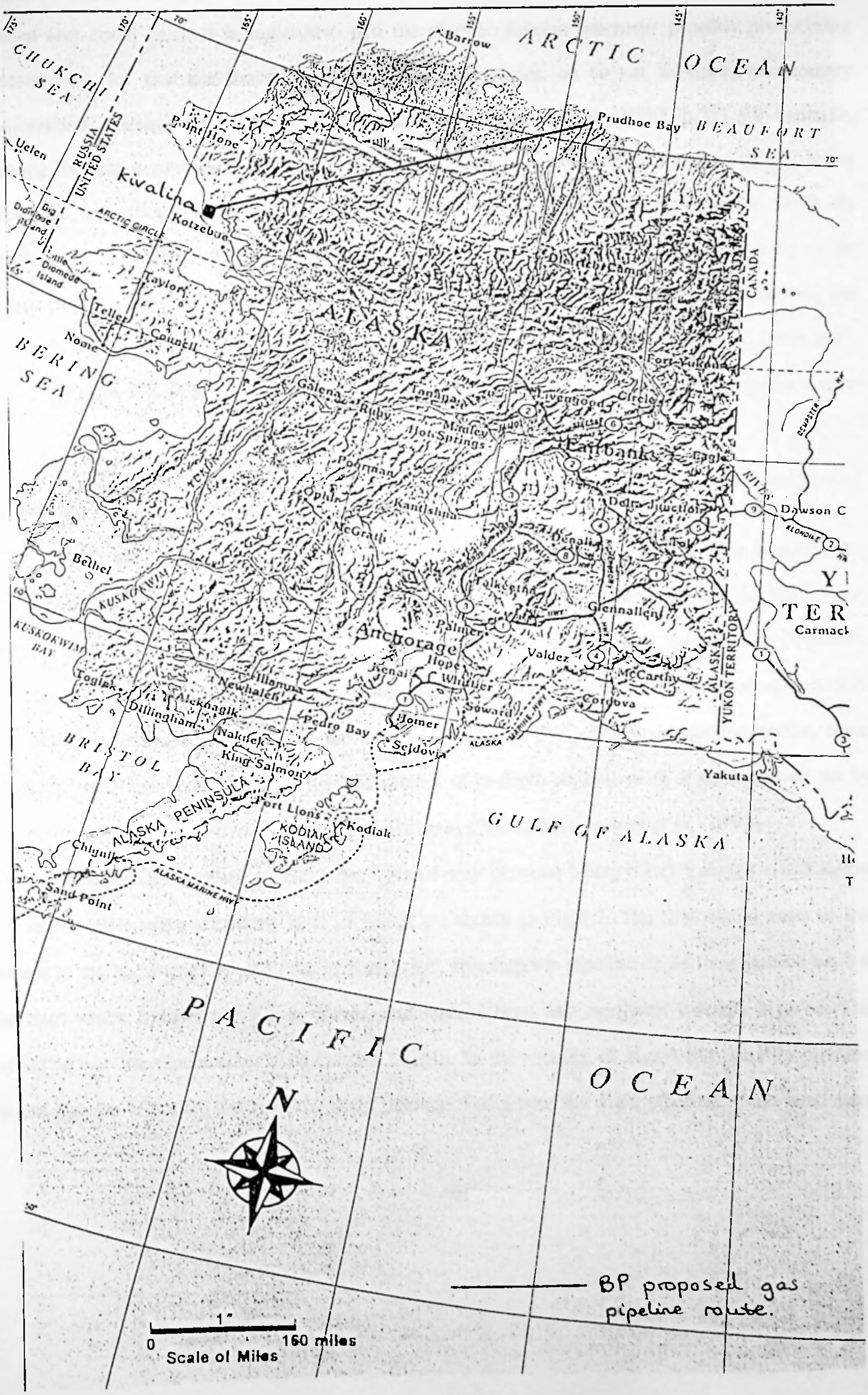
Figure 5.1 Schematic map of the BP Alaska gas pipeline proposal. Source: Holleyoak, 1994.



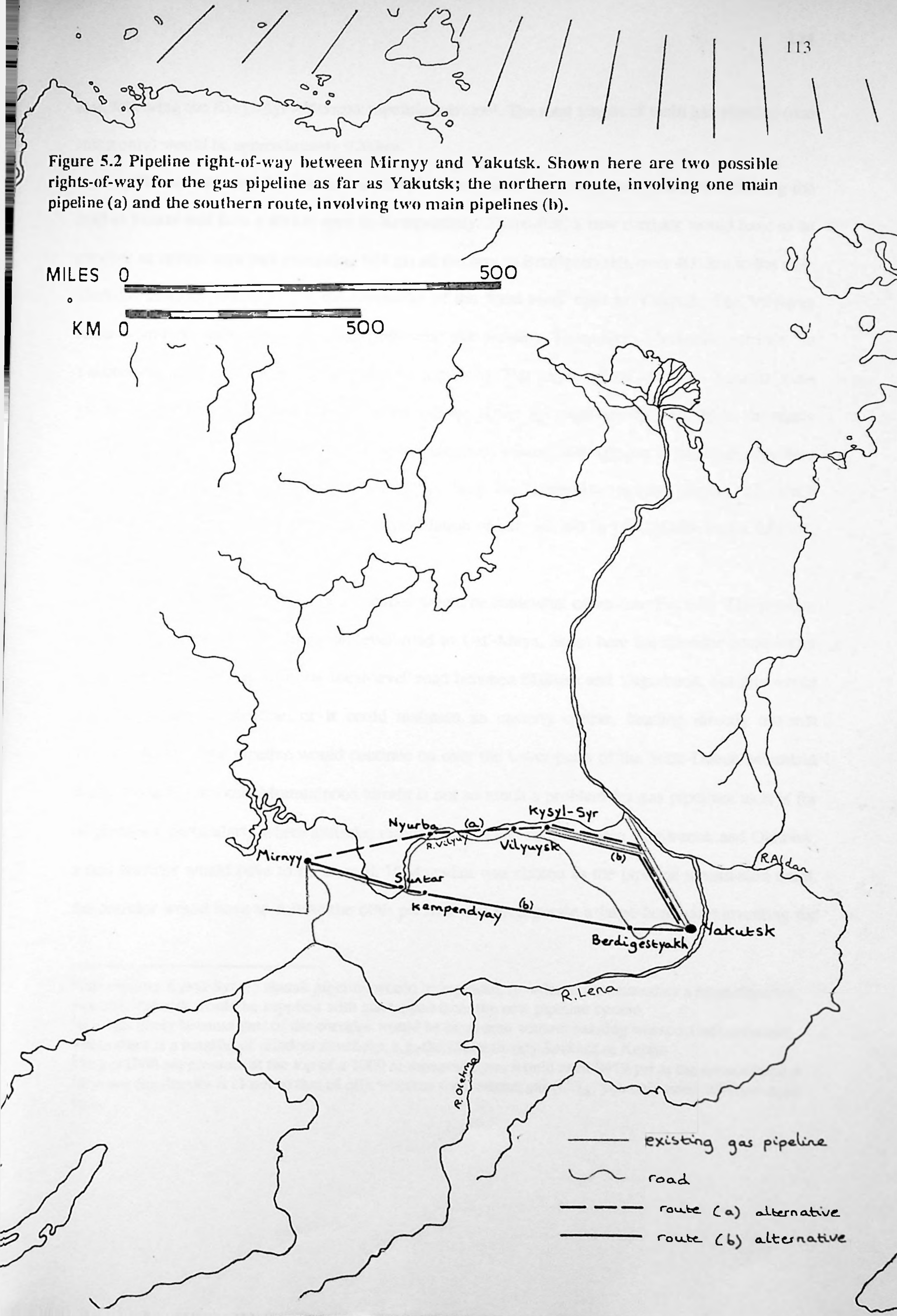
routes, but the following parameter can shed light upon more favourable localities through which a right-of-way could pass. It is imperative that the pipeline follows wherever possible pre-existing rights-of-way, for example those for roads or other pipelines, so as not to cause unnecessary environmental damage in the opening up of new corridors. Turbina (1980, p.31) for example, studying the area between the Khanchaly and Kenkeme rivers, revealed that a variety of vegetation types, e.g. red whortleberry and mosses, did not re-establish themselves everywhere along the corridor cleared for the Taas-Tumus - Yakutsk pipeline. The loss of vegetation and break-up of the surface caused a dramatic change in the heat exchange regime and the depth of seasonal thawing has been increased by 1.2 to 1.7 times. The Corridor Concept, as it is known (Williams, 1989, p.81; Mazur, 1993, p.12), is a measure that has of course been ignored in West Siberia. Pipelines must use:

"...common corridors for transportation, power transmission and communications." (IUCN, 1993, p.40).

These are clearly at a premium in central Sakha, but three obvious ones come to mind. The first is the Mirnyy - Yakutsk road; the second is the Yakutsk - Ust'-Maya road and the third is the Kysyl-Syr - Yakutsk gas pipeline. Apart from eliminating the need for new right-of-way clearance, as well as the detrimental consequences of this, soil and permafrost characteristics on these corridors will not be a complete mystery. In the case of the Kysyl-Syr - Yakutsk pipeline sector, these characteristics have been subject to a small number of in-depth studies, most of them carried out by the *Institut Merzlotovedeniya*, Yakutsk (e.g. Turbina, 1980 and Kamensky *et al.*, 1993).

Bearing this concept in mind, the right-of-way between Mirnyy and Yakutsk could follow one of two alternative corridors, both of which are shown in Fig.5.2. The first would more or less adhere to the 'local-level' road as far as Kysyl-Syr, although the pipeline could miss out the bend in the road which follows the Vilyuy River, and instead head east northeast towards Nyurba. This would reduce the distance by a significant margin. In the vicinity of Kysyl-Syr, smaller pipelines would link the Vilyuyan fields to the main pipeline. From here the main pipeline would head south

Figure 5.2 Pipeline right-of-way between Mirnyy and Yakutsk. Shown here are two possible rights-of-way for the gas pipeline as far as Yakutsk; the northern route, involving one main pipeline (a) and the southern route, involving two main pipelines (b).



east, following the Kysyl-Syr - Yakutsk pipeline corridor[3]. The total length of main gas pipeline (one string only) would be approximately 920 km.

The second corridor, much less likely[4], would head south west from Mirnyy following the road to Suntar and then a 40 km spur to Kempendyay. Thereafter, a new corridor would have to be cut over an upland area (not exceeding 444 m) all the way to Berdigestyakh, over 400 km to the east. Then the corridor would follow the remainder of the 'local-level' road to Yakutsk. The Vilyuyan fields would be served by a pipeline following the existing Kysyl-Syr - Yakutsk corridor. In Yakutsk, the gas from both regions would be combined. The length of the Mirnyy - Yakutsk main gas pipeline would be approximately 860 km and the Kysyl-Syr pipeline; 400 km. From the safety point of view, this alternative does have the advantage of passing through one of the least populated areas of central Sakha; between Kempendyay and Berdigestyakh (Gornyy *rayon*, of which Berdigestyakh is the district centre, had a population of only 10,200 in 1990 (*Goskomstat* RSFSR, 1990, p.47)).

After Yakutsk, selection of a corridor would be somewhat easier (see Fig.5.3). The pipeline would follow the 'republic- / regional-level' road to Ust'-Maya. From here the corridor could either veer north east to link up with the 'local-level' road between El'dikan and Yugorenok, but this would add mileage to the pipeline, or it could maintain an easterly course, heading directly towards Yugorenok. Then the pipeline would continue on over the lower parts of the Sette-Daban Mountain Range towards Okhotsk. Mountainous terrain is not so much a problem for gas pipelines as it is for oil pipelines, particularly where altitudes rarely exceed 1500 m [5]. Between Yugorenok and Okhotsk, a new corridor would have to be cleared. If Magadan was chosen as the pipeline termination point, the corridor would have to follow the 60th parallel and incorporate a large bend circumventing the

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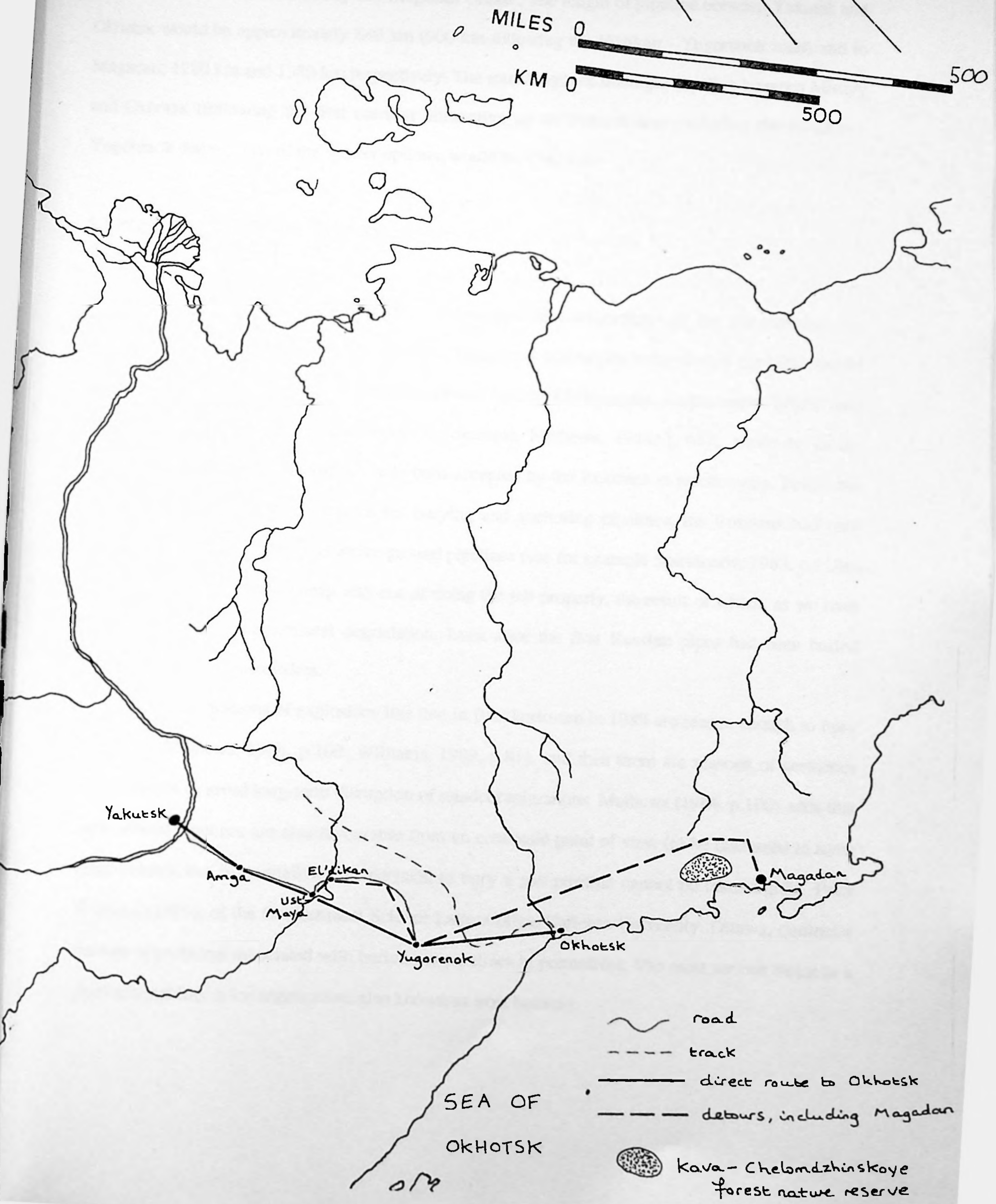
[3]The existing Kysyl-Syr - Yakutsk pipeline would be replaced, in order to accommodate a large diameter pipeline. Yakutsk would be supplied with gas tapped from the new pipeline system.
[4]It is less likely because part of the corridor would be in an area without existing transport infrastructure, where there is a handful of reindeer *sovkhozy*, e.g. the Maltaninskiy *Sovkhoz* at Keptin.
[5]To get 1000 psi pressure at the top of a 1000 m mountain, you would need 2419 psi at the mountain base for water (its density is closer to that of oil), whereas for methane gas (CH_4) you only need 1070 psi at the base.

Figure 5.3 Pipeline right-of-way between Yakutsk and the Sea of Okhotsk coast.



869,200 hectare Kava-Chelomdzhinskoye forest nature reserve. This lies on the Magadan side of the border between Khabarovsk Kray and Magadan Oblast'. The length of pipeline between Yakutsk and Okhotsk would be approximately 840 km (900 km following the El'dikan - Yugorenok road) and to Magadan; 1280 km and 1380 km respectively. The total length of main gas pipeline between Mirnyy and Okhotsk (following the first corridor alternative up to Yakutsk and excluding the El'dikan - Yugorenok detour), one of the shorter options, would be 1760 km.

5.3 PIPELINE CONFIGURATION

The nature of the construction depends entirely upon the configuration of the gas pipeline, i.e. whether it is laid above, on or below ground. The general philosophy today is that pipelines should be laid underground as far as possible. This view is held by the Russians, most notably *VNIIST* and *Rosneftegazstroy*, as well as westerners (for example, Mathews, 1984, p.100). However, in the context of cold regions this view has only been accepted by the Russians in recent years. Before the appearance of cost-effective methods for burying and anchoring pipelines, the Russians had only contemplated on-the-ground and above-ground pipelines (see for example Spiridonov, 1983, p.1184-1187). This amounted to a cheap way out of doing the job properly, the result of which, as we have seen, was serious environmental degradation. Even after the first Russian pipes had been buried similar damage became evident.

The implications of explosions like that in Bashkortostan in 1989 are reason enough to bury a pipeline (Mathews, 1984, p.100; Williams, 1989, p.81), and then there are reasons of aesthetics and the desire to avoid long-term disruption of reindeer migrations. Mathews (1984, p.100) adds that underground pipelines are also favourable from an economic point of view (to be discussed in some detail below). But in permafrost, the decision to bury a gas pipeline cannot be taken lightly. Peter Williams (1989), of the Geotechnical Science Laboratories, Carleton University, Ottawa, outlines a number of problems associated with buried gas pipelines in permafrost. The most serious threat to a pipeline's stability is ice segregation, also known as frost heaving.

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[illegible] FUTURE CONSIDERATIONS

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[illegible] Carleton University, Ottawa, [illegible] The most serious threat to a [illegible] is from freezing.

5.3.1 The frost heave problem.

When soil freezes, there is a movement of water towards the point where freezing is occurring. This causes a volume increase in addition to the 9% (volume increase) always associated with freezing water. The increase in the soil's volume through the accumulation of this additional water accounts for most of the heaving effect. But what would initiate the freezing in this case? In order to maintain the frozen state of the permafrost, a buried gas pipeline would have to transmit cooled gas, in most cases at a little under 0°C. Piping warm gas through a zone of permafrost would cause formation of thermokarst, as well as the chain of events described in chapter 2, thus causing the pipe to subside, as shown in Fig.5.4, and perhaps fracture. Cooled gas transmission is unlikely to cause serious problems in a region of continuous permafrost. But in reality it is highly unlikely that one would be able to lay a long-distance gas pipeline without encountering any discontinuous permafrost somewhere along the right-of-way. While the largest gas deposits lie in the continuous permafrost zones of the far north, markets are situated many hundreds of kilometres away in areas free from permafrost, well to the south of discontinuous or sporadic zones. Once the chilled gas pipeline enters the discontinuous permafrost zone, it risks freezing pockets of unfrozen ground, which incidentally become progressively larger as one moves further south. When this happens, heaving is likely to become a serious cause for concern. As explained in chapter 2, chilled pipelines in West Siberia have been heaved right up out of the soil.

The *uniform* heaving of a pipeline over considerable distances is not considered especially worrying in terms of the pipeline's integrity (Williams, 1994). There is little doubt that the consequences for the *environment* would be severe in any case since large-scale erosion would occur over a number of years, leading to the formation of ravines. The sectors of pipeline most at risk from heaving are those located at the boundaries of areas where there are variations in soil texture uniformity, moisture availability and permafrost continuity ('thermal transition'). These are the areas in which differential heaving takes place and, as Nixon *et al.* (1990, p.303) hasten to add, it is the bane of everyone designing gas pipelines for permafrost regions. Under a differential heaving

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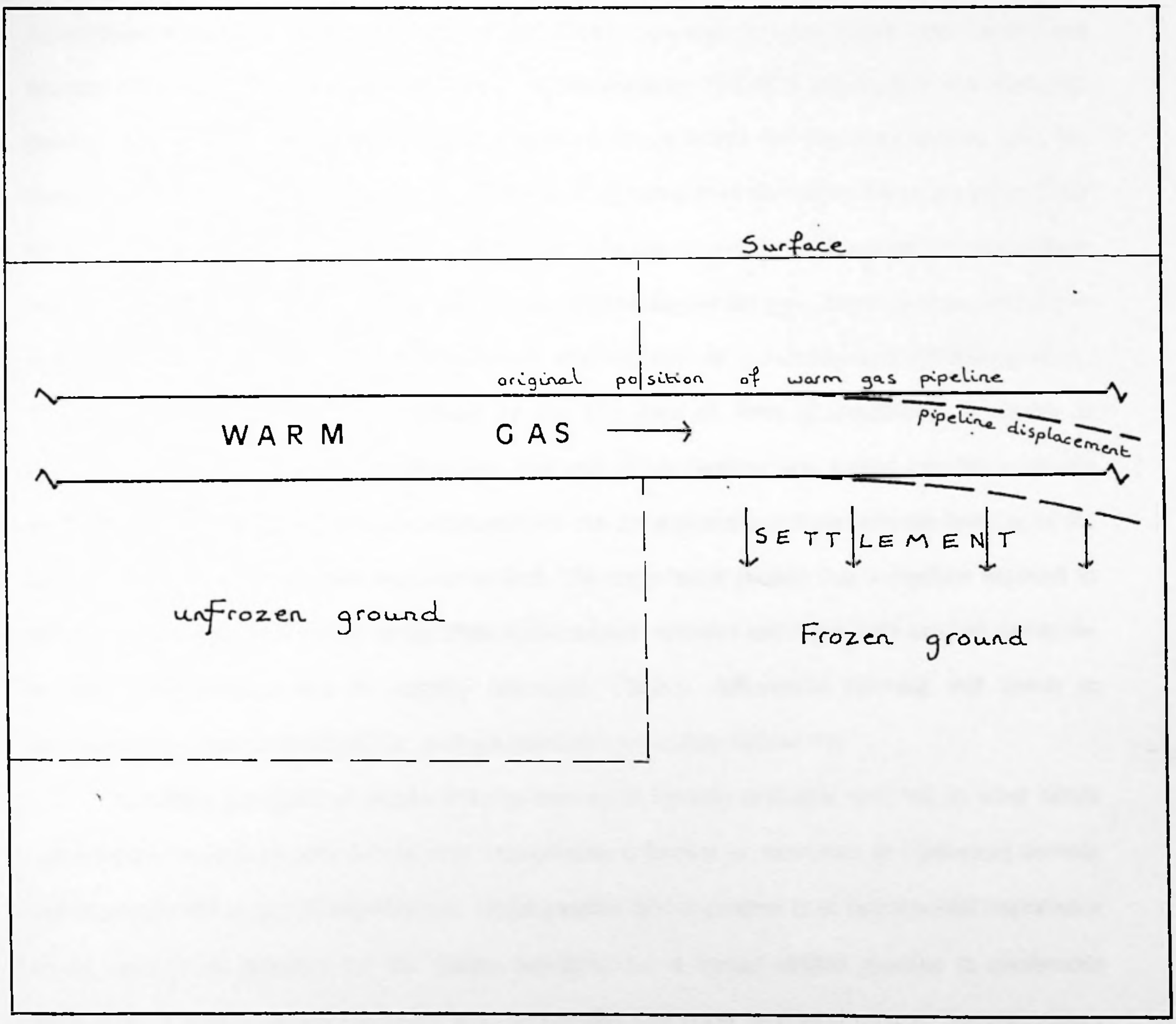
Figure 5.4 Pipeline settlement. The pipeline has settled as a result of the formation of a thermokarst depression. The warm gas pipeline has melted the ground ice, which can constitute more than three quarters of the soil volume.



scenario, serious deformation of the pipeline could result, leading to a catastrophic rupture and an explosion.

Let us examine briefly the case of heaving in the context of chilled gas pipelines and soil variability. The key investigations into heaving under these circumstances have been carried out by a team of French and Canadian scientists working at the *CNRS* (*Centre National de la Recherche Scientifique*) *Centre de Géomorphologie*, Caen, France. A series of experiments were carried out between 1982 and 1989 which involved observing deformations of a 16 m length (273 mm diameter) pipeline, half of which had been buried at a depth of 33 cm in silt and the other half in sand, the former being finer-grained and more susceptible to frost heave than the latter. These are collectively known as the SS experiments. The pipe carried gas between -2 and -5.25°C and the air temperature was -0.75°C (see Fig.5.5). In the first experiment, deformation of the pipe resulting from frost heave in the silt soil was observed almost immediately after the flow of gas commenced (Williams *et al.*, 1992, p.42). This deformation continued for the 276 days of freezing conditions, as shown in Fig.5.6. This result has serious implications. One end of the pipeline was locked into the relatively stable frozen sand and so could not compensate for the deformation resulting from the heaving of the silt soil into which the opposite end was locked. The experiment proved that a pipeline exposed to differential heaving (in this case where there is a transition between soil types with marked variations in frost susceptibility) can be rapidly deformed. Clearly, differential heaving will result in considerable stresses in the pipeline, perhaps causing it to rupture ultimately.

A chilled gas pipeline clearly induces heaving in initially unfrozen soil, but to what extent will heaving occur in already frozen soil? This process is known as secondary or continuing heaving and was observed in the SS experiments. Consideration of this process is of fundamental importance to the scenario in question for the Sakha Republic, i.e. a buried chilled pipeline in continuous permafrost. It is known that thermally induced heaving will occur in frozen ground, but uncertainty still surrounds the band of sub-zero temperatures at which it will occur. If water is confined in very small spaces, for example in soil pores, it will remain liquid below 0°C due to a depression of the freezing point (Williams, 1989, discusses this matter in depth throughout his book). But how far

Figure 5.5 Diagram of the SS (Silt / Sand) experiment test facility. Source: Riseborough *et al.*, 1993.

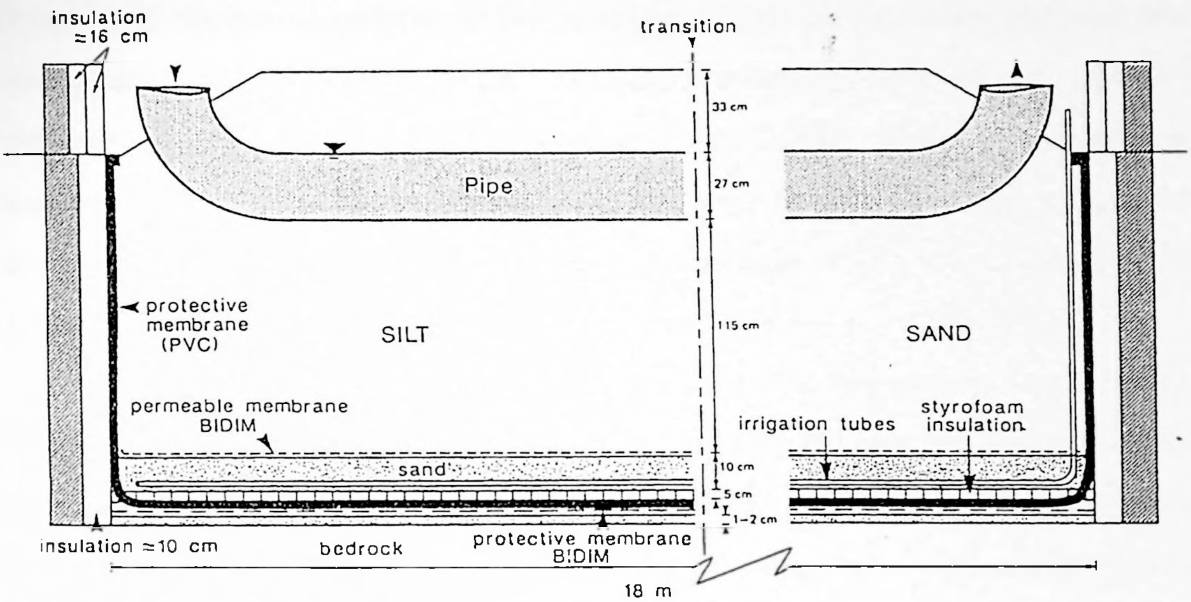
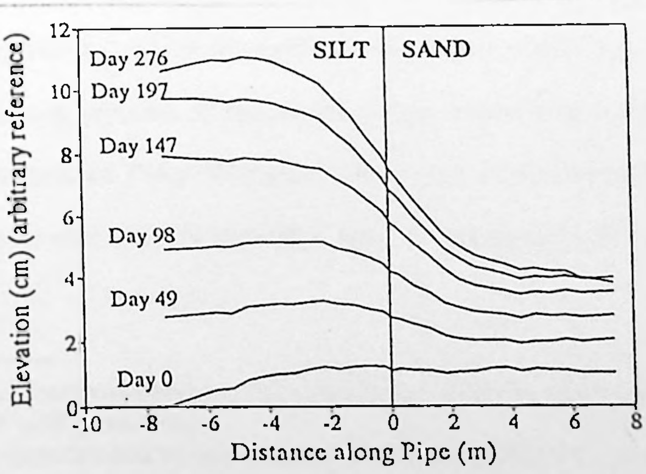


Figure 5.6 Displacement of the pipeline in the SS (Silt / Sand) experiment (first cycle). Source: Williams *et al.*, 1992.



below 0°C will water remain liquid and thus be able to migrate? According to Williams (1986, p.154; 1989, p.104-105), some believe that the soil has to be around 0°C for significant migrations to occur, while others believe that water migration can take place down to -5°C, e.g. Parmuzina (1980, p.135). The Russians and Chinese (the proponents of well-below-zero water migration) have not been able to provide evidence to suggest that water will migrate below about -2°C (Williams, 1994) and so one would have to say that continuing heaving could be a problem only in zones of 'warm' (-2°C+) permafrost. This phenomenon would not cause large displacements of pipelines, but if it took place in a region of variable soil types or hydraulic conductivity[6], uneven and potentially damaging differential heaving could result (Nixon, 1987, p.260; Nixon *et al.*, 1990, p.302).

Continuing heaving was also observed in the most recent experiments (1990 to 1993) carried out at the Caen test site. These concerned differential heaving at boundaries between unfrozen and prefrozen silt soil (hence the experiments' collective name UP), simulating the 'boundary' between unfrozen and frozen ground within a zone of discontinuous permafrost. An insulating wall was constructed along the midpoint in the laboratory to allow initial freezing of the 'prefrozen' section. The air temperature for the frozen ground was kept at -0.75°C, while pipe temperatures varied between -5 and -8.5°C during the experiment when gas flowed through the pipe. Before the experiment, it was presumed that this would provide a more extreme case of pipe distortion than in the SS experiment because the prefrozen soil would provide a stiffer restraint to pipe movement. This was indeed found. Unfortunately, during the first freezing localized basal thawing occurred in the prefrozen side of the experiment[7] which allowed the pipe to tilt, rather than bend (see Fig.5.7). This had the effect of reducing pipeline strain as this tilting compensated for the heave in the unfrozen section. In the opinion of Peter Williams (1994), one of the team members, had this thawing not occurred pipeline strain would probably have exceeded that observed during the SS

[6]Hydraulic conductivity is temperature dependent. Thus, variations would occur between zones of so-called 'warm' (relict) permafrost and 'cold' permafrost.
[7]Some heat from beneath the experimental trough managed to penetrate the prefrozen sector during this experiment.

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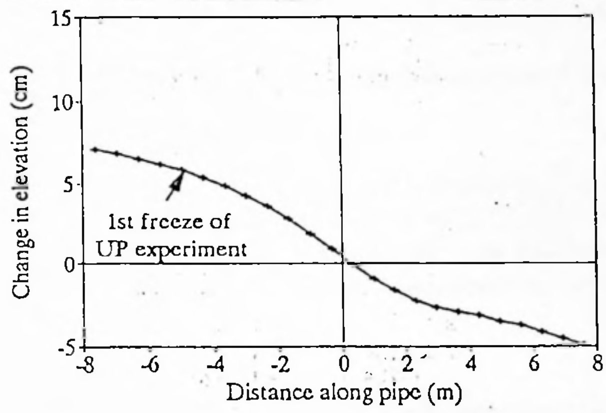
experiments. The build up of strain on the pipeline had ,in fact, been more rapid before the thawing than in the SS experiments.

Figure 5.7 Displacement of the pipeline in the UP (Unfrozen / Prefrozen soil) experiment (first cycle). Note the tilt in the prefrozen section. Source: Riseborough *et al.*, 1993.



Given that significant secondary heaving is unlikely to occur below -2°C (Williams, 1994), what chance is there of heaving in any form occurring in central Sakha where, as we have seen, permafrost is continuous? If one averages each set of figures for the predominant range of annual temperatures at the base of the seasonally fluctuating layer (as listed in chapter 4), it becomes clear that there are few cases in which this average exceeds -2°C. In only one case does this average figure come close to -1.0°C (in zone 3) [*alas*] it is -1.1°C). In three zones it is -1.75°C [8]. Where heaving under natural conditions has been observed, as noted under each transect zone in f), it is likely to have occurred in temperatures higher than those of the predominant range, perhaps at shallower depths in the active layer. It is worth noting that the underground section of the Kysyl-Syr - Yakutsk

[8]In terrain zone 2) of the Yakutsk to Solnechnyy transect the figure is -0.8°C but there are no soils susceptible to heaving here.

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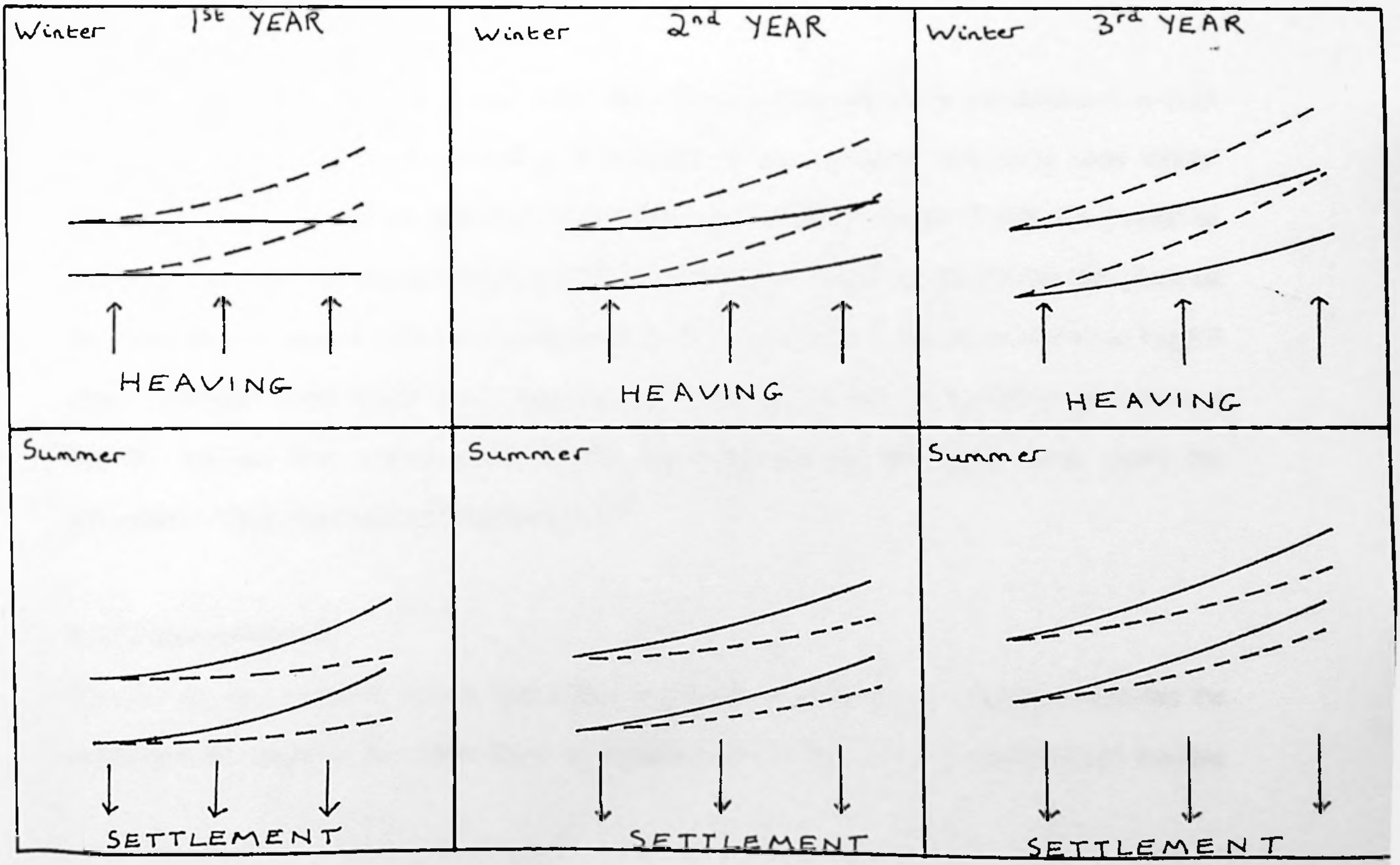
pipeline is buried at less than one metre, well within the active layer (Kamensky *et al.*, 1993, p.323). To compensate for the thawing, the gas is transmitted at above-zero (0.2 - 2.5°C) temperatures during summer. But this does not stop the frost heaving that takes place when the thawed layer freezes in winter (when the gas is transmitted at -6.7 - -7.6°C). Annual vertical displacement of the underground pipeline section[9] is between 1 and 10 cm. In summer the pipeline settles, though does not return to its exact pre-heaving position. Over a number of years, the cumulative result is that the pipeline is jacked up, as shown in Fig.5.8. The jacking effect was even observed in sandy areas. Hence, the risk of pipeline damage could be reduced by burying the pipeline below the depths where heaving has been observed. This should be possible, given that the active layer rarely exceeds 2 m.

Figure 5.8 Pipeline Jacking. The result of heaving and settlement of a pipeline over a numbers of years. By the summer of the 3rd year the pipeline is clearly deformed in comparison to its original position in the winter of the 1st year. The straight line represents the pipeline position at the beginning of the season, while the dashed line represents the pipeline position at the end of the season.



[9]The maximum vertical displacement of the surface-laid pipeline section is 23 cm on the *mari* swamps.

However, areas surrounding large rivers or lakes will almost certainly experience average temperatures closer to 0°C, particularly if taliks are known to exist, and *would* therefore be susceptible to some heaving. Clearly, any attempt to avoid every large river in central Sakha would be a Herculean task. Continuing heaving *per se* would not be a threat to the pipeline but wherever there are transitions between soil textures, particularly in those areas with ground temperatures close to 0°C, differential heaving could occur and thus cause some deformation of the pipeline. However, sand is predominant throughout the region and marked differential heaving can be avoided if the pipeline keeps to sandy zones as much as possible. Mixed sand and clay *supes* and *suglinok* silts are obviously a serious cause for concern (Williams, 1994). The clay element exerts great 'suction' forces, i.e. drawing in water from adjacent areas, while the sand is highly permeable. A chilled pipeline passing through an area of such silts, and near a large river, could induce substantial differential heaving within very confined areas. A study carried out by S.A.Zamolotchikova in the Kenkeme river valley in 1974 showed that the Taas-Tumus - Yakutsk pipeline was heaved out of *suglinok* and *supes* soils (total diameter of observed heaving was between 20 and 50 cm) (Turbina, 1980, p.32).

There is only one minute area on the right-of-way where conditions are conducive to both secondary and normal heaving, as well as differential heaving, on scales that could cause serious pipeline deformation. This lies near the Sea of Okhotsk coast, where islands of unfrozen ground lie within a narrow band of discontinuous permafrost. Marked differential heaving could take place on the boundaries of these islands, i.e. between the unfrozen and frozen ground, as shown in Fig.5.9 (this is probably what would have happened had the prefrozen side of the UP experiment not thawed). Perhaps less serious would be the secondary heaving that could occur where the temperature of the frozen ground approaches 0°C.

5.3.2 Other problems.

Data for the two transects reveals that slopes are prone to solifluction, a process involving the downslope movement of the active layer in particular due to the effects of freezing and thawing

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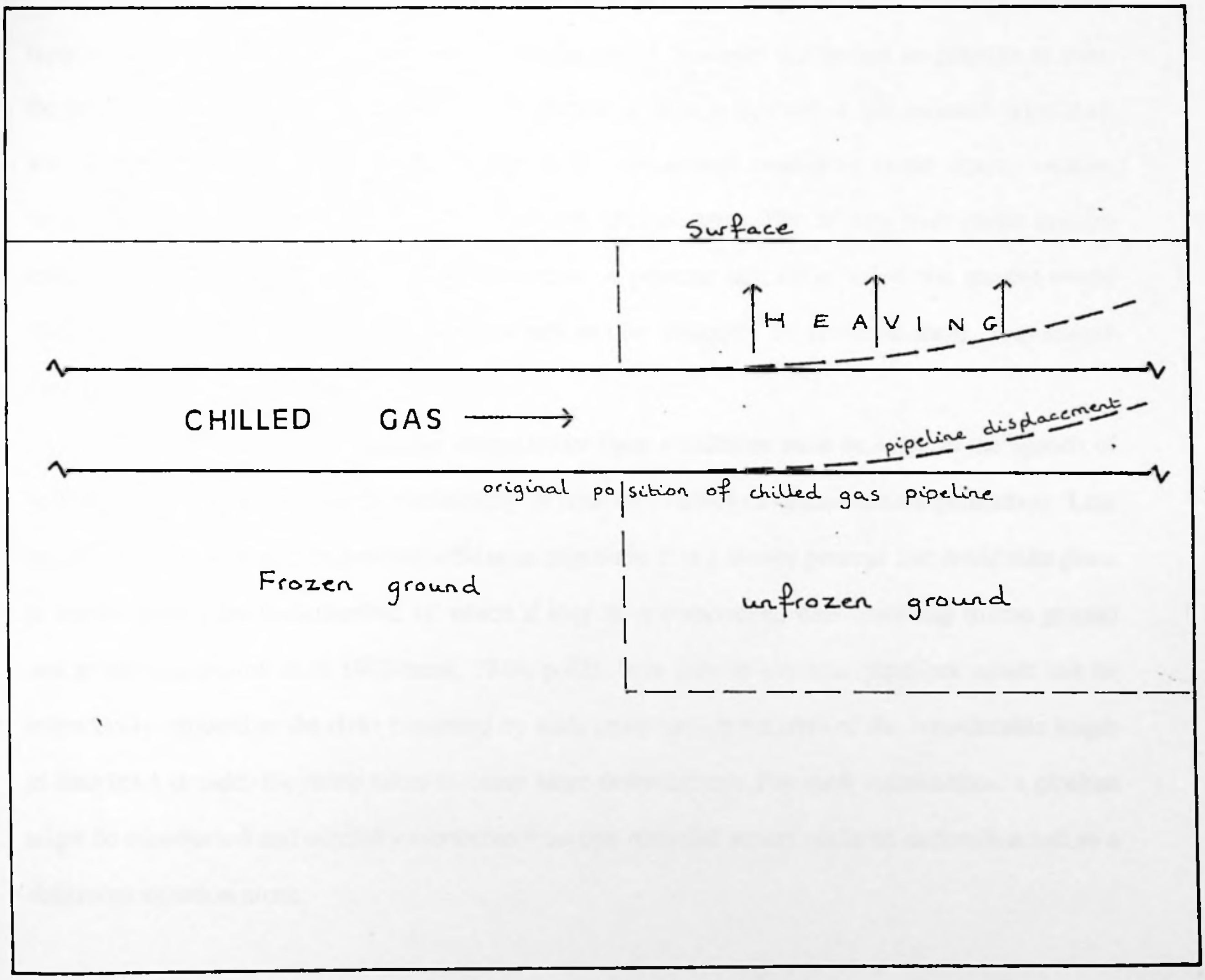
Figure 5.9 Displacement of a chilled gas pipeline at the border of frozen and unfrozen ground due to thermally induced differential heaving (possible scenario).



combined with gravity. Where a pipeline is laid within the active layer, parallel to the slope gradient, it would be at risk from pressures exerted by the soil piling up on the upslope side. These pressures could be averted by laying the pipe at right angles to the slope. But in this case, the pipe could be susceptible to loss of support. This would result from the erosion of soil loosened by the cooling effect of the pipeline. The newly eroded gully would be progressively deepened by water channelling, causing serious support loss and pipeline deformation, as shown in Fig.5.10.

In central Sakha these processes are unlikely to penetrate deeper than say 2 m (the seasonal layer, or active layer, does not often exceed 2 m in depth). It would not always be possible to bury the pipeline below this layer, especially on the banks of large rivers where the seasonal layer may transcend the 2 m norm. Where this is the case, 'deep-seated' landslides could occur, causing catastrophic damage to a pipeline buried within the affected area. This is why river banks present special problems for northern pipeline construction. A pipeline laid on or above the ground would also be at risk. Discontinuous permafrost zones would obviously be prone to these 'deep-seated' landslides.

Clearly, research into pipeline design under these conditions must be high on the agenda of northern pipeline planning teams, particularly in relation to zones of discontinuous permafrost. Less is known about creep and its possible effects on pipelines. It is a slower process and could take place at depths greater than solifluction, of which it may be a component, thus involving frozen ground and greater masses of earth (Williams, 1989, p.82). It is safe to say that pipelines would not be immediately exposed to the risks presented by such creep mainly because of the considerable length of time (ca.1 decade) the creep takes to cause large deformations. For such eventualities, a pipeline might be constructed and carefully monitored[10] so that remedial action could be undertaken before a dangerous situation arose.

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[10]Internal monitoring of the pipeline would be carried out using 'intelligent pigs'.

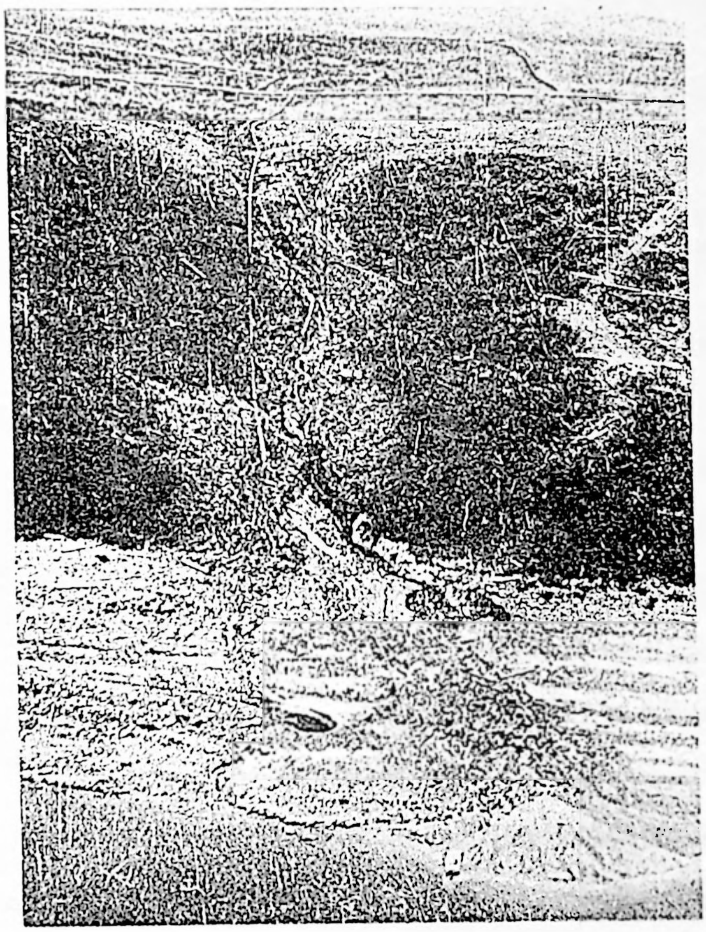
[illegible]

[illegible]

[illegible]

[illegible]

Figure 5.10 Catastrophic pipeline deformation on an eroded river bank. Source: Kondratyev, 1983.



One other process, stress concentration, is well known to engineers. However, in the context of chilled pipelines in permafrost this process has not received close attention even though it could pose a serious threat to pipeline stability. Within a zone of variable soil types, there will be some locations in the ground where the grip on the pipeline is stronger than in other areas, for example where the soil is highly organic. Hence, there will be an uneven distribution of points where the pipeline is being supported. Not only will these points carry most of the pipeline weight, but heaving would be concentrated around them. The implications of this are clearly serious.

5.3.3 Conclusion.

Kamensky *et al.* concluded their paper:

> *"A long period of observation on the* [Kysyl-Syr - Yakutsk] *gas pipeline showed that the underground method of pipe laying is the most proper for the conditions of Central Yakutia ensuring the stable temperature regime of the gas pipeline."* (1993, p.323).

A buried pipeline between Mirnyy and the Sea of Okhotsk coast appears to be a relatively safe option chiefly because the right-of-way would be almost exclusively within continuous permafrost. A pipeline buried at a depth of 2 m would avoid substantial secondary heaving. There are only two areas in which a pipeline could experience substantial deformation (for reasons already explained). The first is near lakes and rivers in the continuous permafrost zone of central Sakha; the second is in the very small zone of discontinuous permafrost in Khabarovsk Kray. In these areas the permafrost is likely to be 'warm' (close to 0°C) and so it would probably be advisable not to chill the gas considerably below 0°C. By conforming with this advice, one would reduce the risk of initiating frost heave in such 'warm' permafrost. Measures to counteract the undesirable effects of a chilled pipeline buried in discontinuous permafrost will be suggested in the following section.

In the opinion of Peter Williams (1994), the most serious problem facing a pipeline laid in this region[11] would be the occurrence of large-scale landslides. These would only occur within the two aforementioned areas, on the banks of large rivers and where there are large areas of unfrozen

[11] Of course, this applies to any northern region with similar permafrost characteristics.

One other process, frost concentration, is well known to engineers. However, in the context of chilled pipelines in permafrost this process has not received close attention even though it could pose a serious threat to pipeline stability. Within [illegible], there will be water locations in the ground where the gaps on the [illegible] where the soil is highly [illegible] pipeline is being supported. Not only [illegible] would be concentrated around them. The [illegible]

8.5.3 Conclusion.

Razumov et al. concluded their paper:

"A long period of observations [illegible] that the underground method of pipe laying [illegible] conditions of Central Yakutia [illegible] the temperature regime of the gas pipeline." ([illegible], p. 32[illegible]).

A buried pipeline between Nadym and the east of [illegible] would appear to be relatively [illegible] quite clearly because the depth of [illegible] would be almost completely within continuous permafrost. A pipeline buried at a depth of 2 m would avoid substantial secondary heaving. There are only two areas in which a pipeline could experience [illegible] already [illegible]. The first is near [illegible] the continuous permafrost zone in central Siberia, the second is in the very small zone of discontinuous permafrost in Krasnoyarsk Kray. In these areas the permafrost is likely to be [illegible] close to 0°C and so it would probably be advisable not to chill the gas temperature below 0°C. By [illegible] with this advice, one would reduce the risk of [illegible] where [illegible] such warm permafrost. Measures to counteract [illegible] buried pipeline in discontinuous permafrost will be suggested in the following section.

In the opinion of Peter Williams (1998), the most serious problem facing a pipeline laid in this region[1] would be the occurrence of large-scale landslides. These would only occur within the [illegible] areas, on the banks of large rivers and where there are large areas of unfrozen

[1] In [illegible], this applies to any northern region with similar permafrost characteristics.

ground. There is no doubt that research into chilled pipeline interactions with mixed soils, such as *suglinok* and *supes*, and with taliks in continuous permafrost zones, especially near large rivers, would be a crucial element of the feasibility study for a gas pipeline traversing central Sakha.

5.4 PIPELINE CONSTRUCTION

The construction phase is likely to cause most of the environmental damage, given that the completed gas pipeline employs the operational regime most suited to local conditions, particularly those concerning permafrost. Hence, particular consideration must be given to planning, especially in this case which involves construction in a relatively undeveloped region with poor infrastructure. Construction planning for northern pipelines is, according to Dimov (1993a, p.18), far from satisfactory. It remains too centralized with much of the planning being carried out in Donetsk and Kiev, both in the Ukraine. These are too far removed from the northern construction sites and Dimov calls for the setting up of regional research planning centres. He suggests one should be formed within *Yakutgazprom* (subsidiary of *Sakhaneftegaz*). Dimov (1993b, p.14) is also dismayed at the lack of cooperative research regarding in particular pipeline stability in unstable soils under permafrost conditions. This problem is being dealt with by the Ukhta branch of *VNIIPKspetsstroykonstruktsiya* alone. Work into solving such pressing problems as this must be shared by as many institutes as possible. He also recommends increasing cooperation with foreign firms in this respect.

5.4.1 Delivery of equipment and supplies to construction sites.

It should be remembered that the majority of the equipment and materials used for a pipeline construction project of this scale would come from the east. Large companies from Japan, South Korea, the United States and other countries seeking 'clean' energy resources would be key investors and part of a single consortium (similar to today's Japanese and South Korean consortia). Russia and [illegible] There is no doubt that research [illegible] pipeline [illegible] with [illegible] soils, such as [illegible] and [illegible] used with [illegible] in [illegible] regions, especially near large rivers, would [illegible] study [illegible]

[illegible]

The [illegible] is likely [illegible] pipeline [illegible] the [illegible] [illegible] [illegible] that [illegible] [illegible] [illegible] [illegible] from the [illegible] [illegible] and [illegible] [illegible] setting up of [illegible] planning [illegible]. He suggests [illegible] should be [illegible] with [illegible] [illegible] [illegible] ([illegible], p. 10) is also [illegible] at the [illegible] research [illegible] as particular pipeline [illegible] in [illegible] with [illegible] conditions. This problem is being dealt with by the [illegible] branch of the [illegible] [illegible] [illegible] [illegible] [illegible] as this must be [illegible] as possible. He also recommends increasing cooperation with foreign [illegible].

[illegible] of equipment and supplies to construction sites.

It should be [illegible] that the majority of the equipment and materials used for a pipeline [illegible] would come from the [illegible] companies from Japan, [illegible] the United States and other countries [illegible] would be [illegible] and part of a single [illegible] (similar to today's Japanese and South Korean [illegible]), [illegible] and the Sakha Republic would also be part of the consortium, so small-scale supplies would come from within the Russian Federation.

Bulk equipment movements into the republic, notably the in-shipment of pipe sections and other supplies, should take place chiefly during the short summer in order to make use of the shallow-draft bulk-carrier vessels that ply the waters between the port of Osetrovo (at Ust'-Kut on the BAM railway) and numerous destinations along the Lena and its tributaries. These waterways will provide access to a number of large settlements from where equipment can be supplied to points along the right-of-way. Vessels will be able to reach Lensk (to supply the Nepa-Botuobian section of the pipeline), Yakutsk (to supply the centre), Vilyuysk (to supply the Vilyuyan region), Amga and Ust'-Maya (to supply the eastern section). Maritime transport would be crucial for the delivery of equipment to the eastern-most portion of the right-of-way, i.e. the Okhotsk / Magadan area. A small number of roads can be used, and given that the pipeline project is unlikely to commence before the end of the millennium, the AYAM railway could be a useful additional transport mode following its completion. Likely scenarios for in-shipments to various sections of the right-of-way are considered below and illustrated in Fig.5.11.

Equipment being brought in to the Mirnyy end of the right-of-way can be shipped on the Lena River to Lensk. From there, equipment can be sent via the all-weather year-round highway to Mirnyy. The equipment should be stock-piled in Mirnyy and during the onset of winter, the final stage of deliveries can be implemented, when access to the most remote parts of the pipeline right-of-way is easier. Vehicles will be able to make use of the vast network of frozen-river 'winter roads'. Rather than using frozen tracks over the permafrost, which will undoubtedly suffer disturbances (leading to thawing) caused by endless convoys, these 'winter roads' should form the transport backbone for the final stages of equipment deliveries to the assembly sites at the right-of-way. This strategy should be applied in all sectors of the right-of-way. If necessary, some deliveries could be made along the road to Yakutsk from Mirnyy.

Deliveries to the central sector of the right-of-way would almost certainly go to Yakutsk, where they could be stock-piled and eventually delivered either westwards, along the road to the

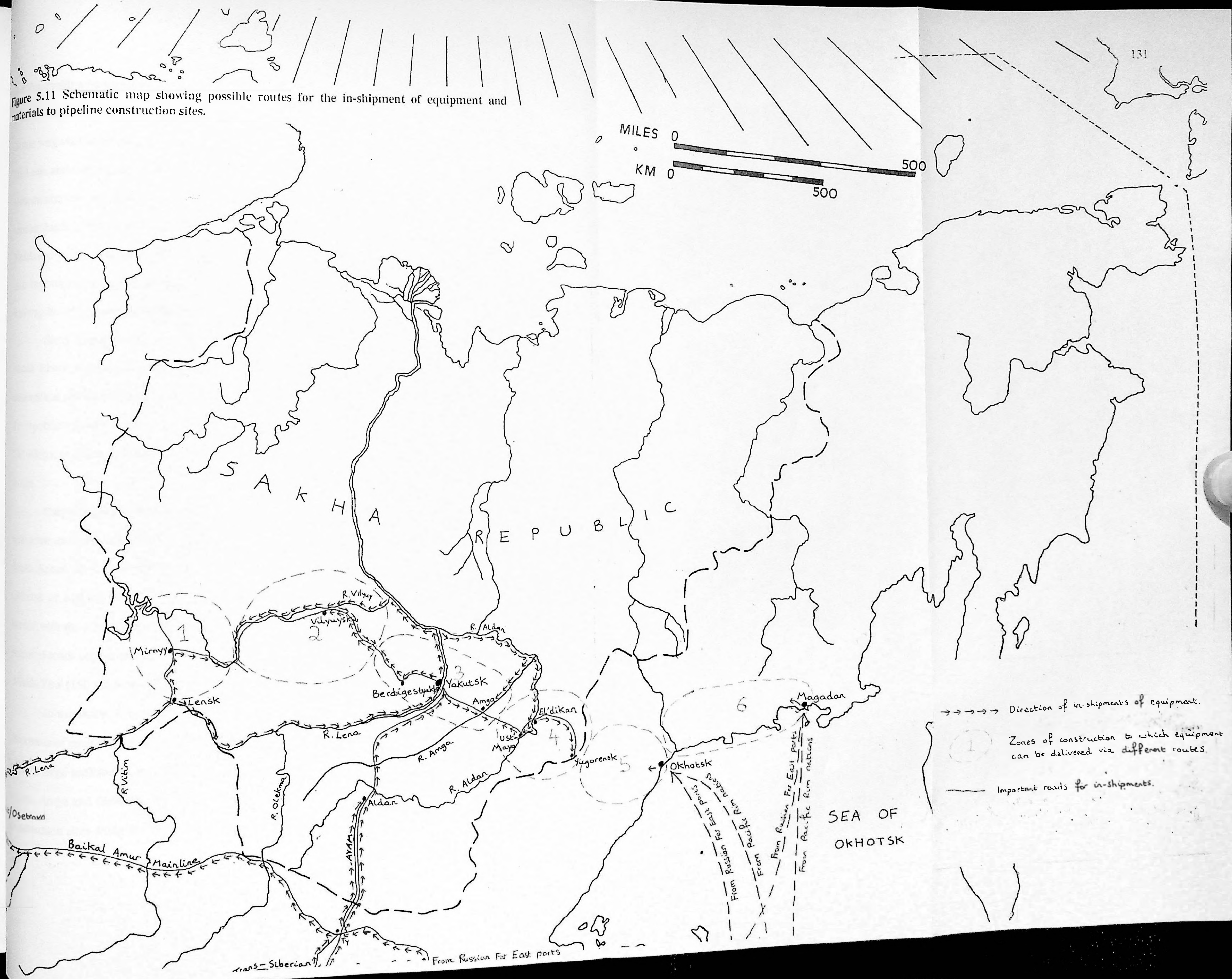


Figure 5.11 Schematic map showing possible routes for the in-shipment of equipment and materials to pipeline construction sites.

Berdigestyakh area and from there along 'winter roads' to construction sites, or eastwards, along the road to Mayya and Amga and 'winter roads'. Large loads destined for Amga could go by river vessel all the way via the Aldan and Amga rivers. Bulk deliveries to the Vilyuyan region would move along the Lena and then up the Vilyuy. Once in the vicinity of Kysyl-Syr, Vilyuysk and Verkhnevilyuysk settlements, there is a small network of 'local-level' roads in addition to potential 'winter roads'. Some smaller loads could be delivered direct from Yakutsk to the Vilyuyan region along the Yakutsk - Verkhnevilyuysk portion of the 'local-level' road which links the capital with Mirnyy. Supplies could also be brought into central districts of the right-of-way along the Never (on the Trans-Siberian Railway line) - Tynda (on the BAM line) - Yakutsk highway.

Similar operations could be used to supply construction sites in the Ust'-Maya district of the Aldan River. Equipment could move down the Lena and then up the Aldan. Provisions for the easternmost sector in the republic could be off-loaded at El'dikan and then taken eastwards towards the republic's border along 'winter roads' or the 'local-level' road to Yugorenok. Further upstream at Ust'-Maya, supplies would be sent westwards along 'winter roads' or the 'regional-level' road towards Amga.

Cargo deliveries to Khabarovsk Kray would follow a different route. During the months with least ice-cover on the Sea of Okhotsk, sea-going vessels would take cargoes direct from Japan, South Korea or even the larger ports of Russia's Pacific coast, e.g. Vladivostok and Vanino, to Okhotsk or Magadan. From either port, equipment would be taken on 'winter roads' towards the border with the Sakha Republic, which lies some 300 km west of Okhotsk. There appear to be no prepared roads of any description in northern Khabarovsk Kray, although a track links Okhotsk with Allakh-Yun' (150 km north east of Yugorenok).

In summary, it is possible to define two delivery phases. The first would involve bulk in-shipments of equipment and supplies during the summer navigation period. Cargoes would be stock-piled in large settlements, e.g. Mirnyy, Yakutsk and Vilyuysk or in smaller settlements such as Ust'-Maya, Amga and Okhotsk. The second, implemented during winter, would involve deliveries to the construction sites along the right-of-way using 'winter roads' or, if necessary, small dirt roads. The

following suggestions should be noted. Larger loads would use river transport wherever possible. Only small loads would be taken by road for a large part of their journey, thus leaving more space on the river vessels for bulkier cargoes. The use of 'local-level' and 'regional-level' roads should be kept to a minimum since there would be a risk of serious disturbance to underlying permafrost. Where overland vehicle movements are unavoidable, special all-terrain vehicles, designed to exert minimum pressure on the ground surface, should be used. Such a vehicle has been designed by *Gazstroymashina* and the Canadian firm Foremost (Shmal, 1993, p.13). It can carry 70 tons whilst exerting a pressure of 0.4 kg per cm^3 on the surface. 'Winter roads' should be used as often as possible for the final legs of journeys to construction sites along the right-of-way[12]. This can be easily implemented given the dense network of large and small rivers within central Sakha.

5.4.2 Construction.

As much construction as possible should be carried out during the winter months (Mazur, 1993, p.12). This applies especially to the digging of trenches for the pipelines in order to avoid exposing the permafrost in summer and thereby inducing large-scale melting and formation of thermokarsts. Observation of this rule is particularly important in those areas where the soil has a very high ice content. Russian pipeline layers have in the past not hesitated to use explosives to open up trenches in the permafrost. The use of slow excavators was undesirable since the aim was to lay pipelines as quickly as possible. To avoid using explosives, *Gazstroymashina* has developed the ETR-307 series of 880 kilowatt rotary bucket excavators which are capable of digging trenches 3.1 m x 3.1 m.

Construction should be completed by the end of the winter season (Dimov, 1993a, p.17). If backfilling[13] has not been completed by summer, thawing of the exposed permafrost will occur and the pipeline could rise to the surface and anchoring devices would be needed to secure the pipeline.

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[12]These 'winter roads' could be reinforced using modifications of the techniques implemented during the construction of the Taas-Tumus - Yakutsk - Bestyakh pipeline.
[13]Once the pipeline has been lowered into the trench and secured, the soil originally removed is replaced in a process called backfilling.

[illegible] suggestions should be noted. Larger [illegible] would [illegible] whenever possible. Only small [illegible] would be taken [illegible] a large part of their [illegible], thus [illegible] space [illegible] purposes. The use of [illegible] and regional [illegible] should be [illegible] to a [illegible] there should be [illegible] disturbance to [illegible]. Wider [illegible] trench [illegible] [illegible] the [illegible] has been [illegible] by [illegible] and the [illegible] [illegible] a [illegible] [illegible] for [illegible] [illegible] be [illegible] given [illegible]

8.8.4 Construction

Although construction as possible should be carried out during the winter months (Mathes, 1993, [illegible]). This applies especially to the digging of trenches for the pipelines in order to avoid exposing the [illegible] to sunshine and drying inducing large-scale [illegible] and formation of [illegible]. Adherence to this rule is particularly important in those areas where the soil has a very high [illegible] content. [illegible] in the past had resorted to use explosives to open up trenches [illegible]. The use of [illegible] was [illegible] since the aim was to lay pipelines as [illegible] as possible. To avoid using explosives, [illegible] has developed the ETR-507 [illegible] with [illegible] which are capable of digging trenches 3.1 m x 2.1 m.

Construction should be completed by the end of the winter season (Mathes, 1993, p.173). If [illegible] has not been completed by [illegible], [illegible] of the exposed [illegible] and [illegible] should [illegible] on the surface and anchoring devices would be needed to secure the pipeline.

[illegible] should be [illegible] using modifications of the techniques [illegible] during the [illegible] of the [illegible] Heilongjiang [illegible]

[illegible] the pipeline has been lowered into the trench and secured, the soil originally removed is replaced in [illegible]

But if cooled gas can be transmitted by the time above-zero temperatures occur, anchoring would be unnecessary, making for a more economically-expedient construction phase (Ivantsov, 1993, p.56).

The low density of gas means that there is a tendency for the pipeline to float. This tendency increases the greater the pipeline diameter. Normally, a cooled gas pipeline will be frozen into the permafrost, as will be the case in Yamal (Ivantsov, 1993, p.56), but if the surrounding soils are weak and organic, as is the case in parts of central Sakha, special anchoring devices are needed to secure the pipe. Traditionally, concrete ballasting and cast iron stabilizers have been used to ensure pipeline stability in Russia. Ivan Mazur (vice-president of *Rosneftegazstroy*) describes new 'frozen-in anchors', the first of which were used on the Yamburg gas pipelines:

> *"Their operation is based upon the principle that the soil around each anchor remains permanently frozen.....It appears that the most rational use for frozen-in anchors is in sectors of gas pipelines laid in perennially frozen ground, where they are equipped with gas cooling stations."* (Mazur, 1993, p.13).

Gennadi Shmal (1993, p.13) endorses the use of these anchors where chilled gas pipelines are laid through continuous permafrost. He also stresses that this is far more cost-effective than traditional ballasting techniques.

Construction of pipeline river crossings is likely to be one of the most awkward tasks during the construction phase along with construction in mountainous zones. However, a relatively new technique for river crossings has been devised that, it is claimed:

> *"....is fast, cost-effective, provides ultimate protection for the pipeline, and most importantly, causes the least disturbance to the environment."* (*VneshTruboProvodStroy et al.*, 1994).

Although originally applied in temperate climates, the process, known as directional drilling, can be used just as successfully in permafrost conditions (directional drilling has been used for three pipeline crossings under the Susitna River in Alaska). The major advantage of this technique is that the pipeline can be laid under the river, thus eliminating explosion risks and the need to construct a bridge to which an above-ground pipeline would have to be attached. As of mid-April 1994,

H.C.Price Co.[14] of Anchorage, Alaska, and Harcro, of Sapulpa, Oklahoma, two leading proponents of directional drilling technology, have been involved in 54 directional drilling projects. The longest crossing so far is ca.1820 m for a 1220 mm (48 in) pipeline (Skonberg, 1993, p.1).

Directional drilling is a two stage process, as shown in Fig.5.12. The first involves the drilling of a small-diameter (ca.130 mm / 5 in) pilot hole along a designed directional path, the drill profile for which is determined by soil core sampling and river profile surveys. Sand and clay, common throughout central Sakha, are two of the three preferred soil types for directional drilling, the other being silt. The second stage involves enlarging the hole and pulling the pipeline all the way through the hole, as shown in Fig.5.13. Work has been carried out successfully at temperatures as low as -40°C, although it is noted that equipment dependability and crew productivity drops dramatically below this temperature. It should also be noted that the operations require large volumes of water, normally drawn from the river. According to Skonberg (1993, p.3) the only environmental and economic drawback of the process is the containment and disposal of the drilling slurry. This is used to cool the drilling bit, lubricate the bore hole and to minimize friction between the hole and the pipeline during pull back operations. Landslide and solifluction dangers, mentioned previously, could be avoided since the directionally drilled pipeline usually descends at angle of 8°, well back from the river bank. Given that the longest crossing drilled so far is ca.1820 m, the widths of the rivers in central Sakha should not be a problem in most cases. However, using this technology to cross the Lena near Yakutsk will not be a simple task, given the numerous channels, sandbars and islands that are so typical of large Siberian rivers, and the constantly changing morphology and course. Ways around these complications could be found, but the question remains, can heaving in sub-river bed taliks be avoided once the chilled gas begins to flow through such a pipeline (which could lie 15-20 m beneath the river bed at its deepest point)?

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[14]H.C.Price Co. and VneshTruboProvodStroy formed a Joint Stock Company in 1992 called VTPS/Price. It has already been awarded a contract by Uzneftegazstroy to use directional drilling for a 1000 m (1020 mm / 42 in) pipeline crossing the Amu-Darya River in Uzbekistan. Completion is scheduled for September 1994 (VneshTruboProvodStroy *et al.*, 1993).

are, [illegible] of Anchorage, Alaska, and [illegible] of [illegible], two leading proponents of [illegible] drilling technology, have been involved in [illegible] drilling projects. The longest [illegible] (Oil [illegible], 1993, p. [illegible]).

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[illegible] such [illegible]. Given that the longest crossing drilled so far is ca. 1800 m, the [illegible] [illegible] should not be a problem in some cases. However, using this technology [illegible] will not be a simple task, given the [illegible] channels, [illegible] and [illegible] typical of large [illegible] rivers, and the constantly changing morphology and [illegible]. Ways around these complications could be found, but the question remains: can [illegible] be [illegible] once the [illegible] begins to flow through such a pipeline system [illegible] the [illegible] of its deepest point?

[illegible] 1992 [illegible] [illegible] in [illegible] is scheduled for September 1994. [illegible] et al., 1993).

Figure 5.12 Directional drilling. The two stages of the process. Source: Skonberg, 1993.

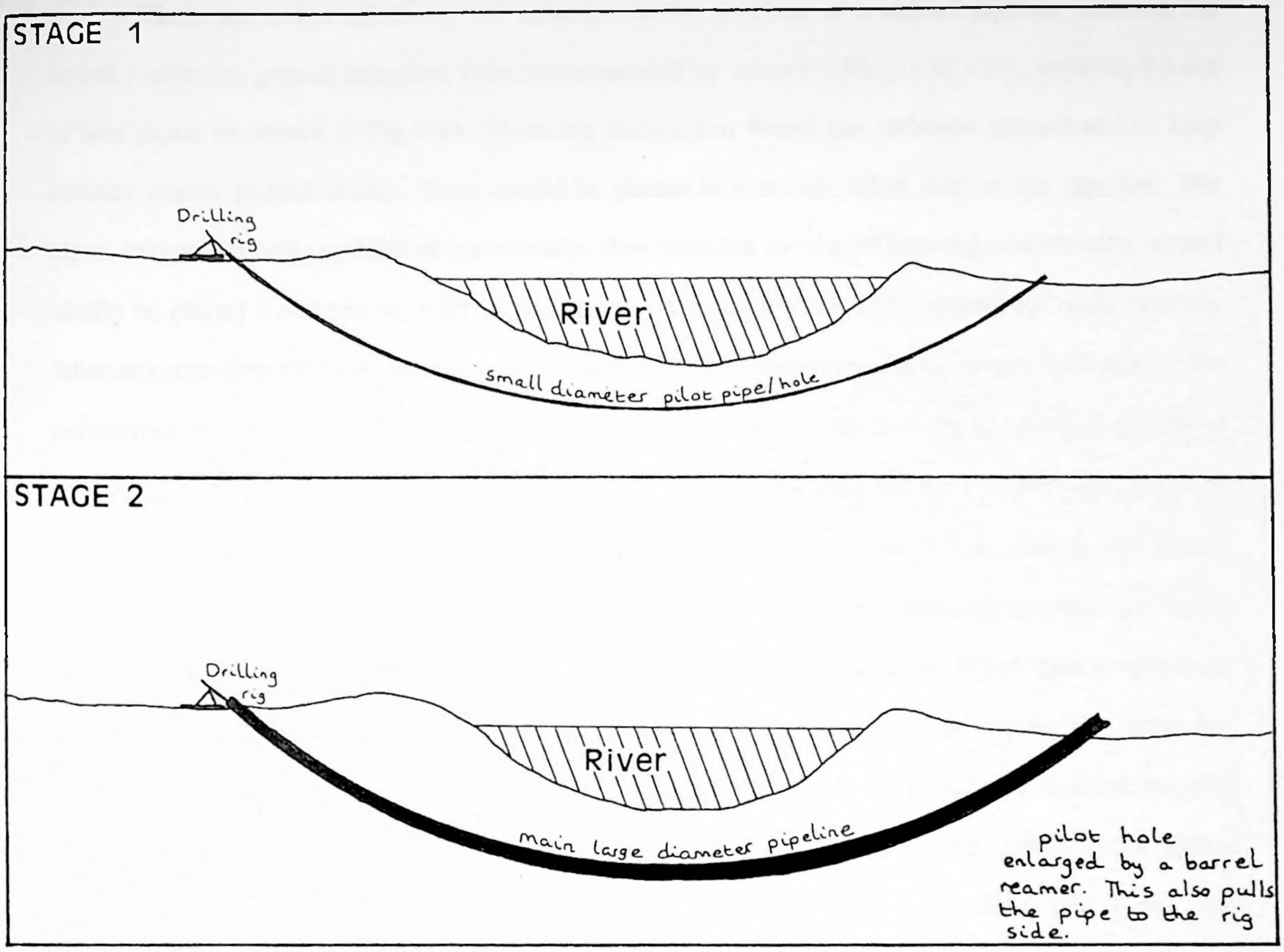
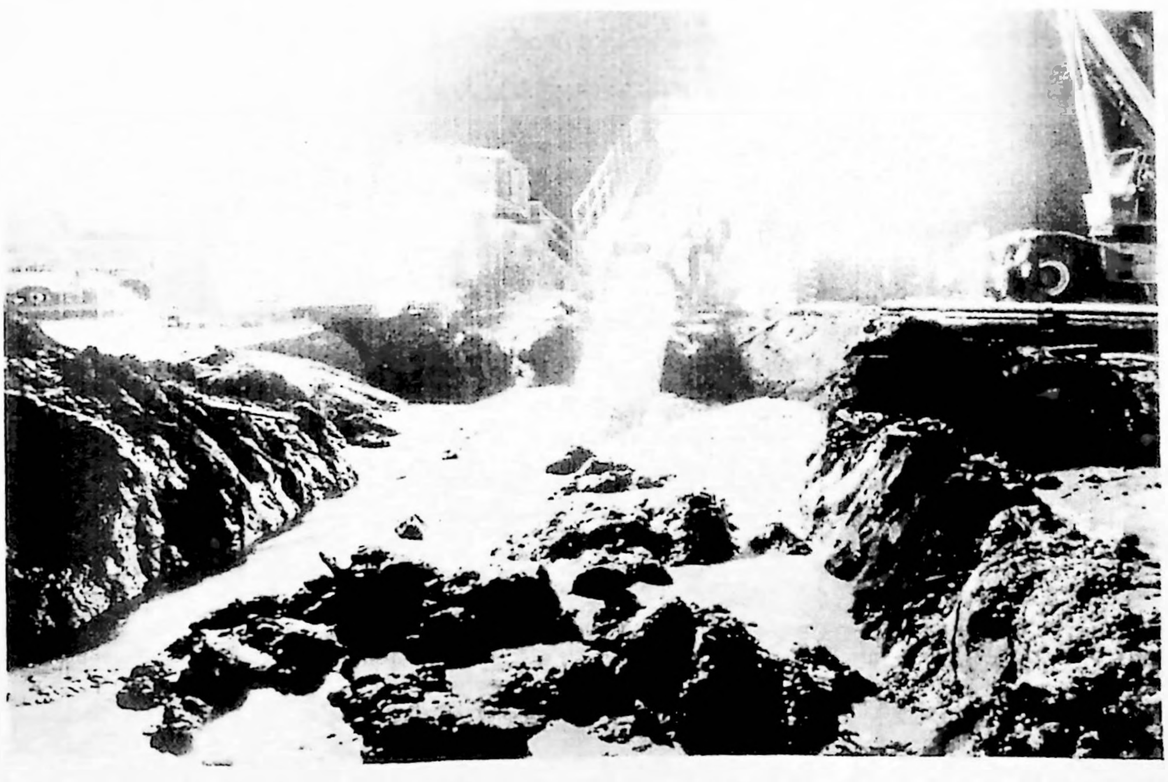


Figure 5.13 Pipe pull through completed. The pipline emerges having been pulled through the a directionally drilled pilot hole. Source: *VneshTruboProvodStroy et al.*, 1994.



There are a few relatively old solutions to the problem of a chilled pipeline crossing the frozen / unfrozen ground interface. One, recommended by Jahns (1984, p.102-103), involves the use of heat pipes, as shown in Fig.5.14. These are designed to freeze any unfrozen ground and to keep initially frozen ground frozen. They would be placed in rows on either side of the pipeline. The pipes, into which heat would flow horizontally, thus reducing the risk of heaving considerably, would ideally be placed 3 m apart in order to maintain a continuous freeze bulb around the main pipeline. Jahns suggests that the pipes would only be needed for short distances - ca.30 m - on each side of the permafrost boundary[15]. He also recommends two measures to prevent heaving in unfrozen ground in discontinuous permafrost. The first would involve insulating the pipeline with a 10-15 cm jacket of urethane, the effect of which is illustrated in Fig.5.15. The second, a radical and possibly unrealistic solution, is called the 'overexcavation' construction mode. During trench digging, an extra half metre would be dug below the expected base of the pipeline and this would be filled with a non-frost susceptible material, such as gravel, or sand. Importing gravel would be expensive, while the development of sand quarries in the Sakha Republic or Khabarovsk Kray would be environmentally unacceptable. If sand happened to be the indigenous soil type along the right-of-way either within talik zones in Sakha or in the discontinuous permafrost zone of Khabarovsk Kray, the implementation of this procedure would probably not be necessary.

The incorporation of a number of compressor stations would be necessary for a pipeline of this length in order to maintain high pressures, particularly at the pipeline termination point where outlet pressures must be at an acceptable level for the liquefaction process; greater than or equal to 800 psi. High pressures are also needed to maintain high outlet velocities, i.e. to sustain a high gas output level. A simple computer programme[16] can be used to calculate the number of compressor stations needed to obtain a desired outlet pressure for a given pipeline length and inlet pressure. Let us consider the following example, which concerns a hypothetical 1000 km (1066 mm / 42 in

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[15]The demarcation of this boundary would not be easy.

[16]BP Exploration has one such programme called the 'Gas Pipeline Pressure Drop Calculator'. Gas temperatures are isothermal (the same along the pipeline's entire length). The programme does not take relief into account.

There are a few relatively old solutions to the problem of a chilled pipeline crossing the frozen/unfrozen ground interface. One, recommended by Lunne (1984, p.102-103), involves the use of heat pipes, as shown in Figure 14. These are designed to freeze any unfrozen ground and/or keep already frozen ground frozen. They would be placed in rows on either side of the pipeline. The pipe line which they would flow [illegible] from [illegible] the risk of heaving would have to [illegible] likely be placed [illegible] apart in order to [illegible] across the main pipeline. Lunne suggests that the pipes would only be [illegible] at [illegible] (Fig. [illegible]) [illegible] the permafrost boundary [illegible]. He also [illegible] to prevent thawing in [illegible] discontinuous permafrost. The first would [illegible] the pipe [illegible] sections, the effect of which is illustrated in Figure 15. The [illegible] solution is called the "[illegible]" mode. During the [illegible] would be laid below the expected base of [illegible] permafrost [illegible] suitable material, such as gravel, or [illegible] gravity would [illegible] the development of [illegible] in the [illegible] deposits in [illegible]. This would be [illegible] unacceptable. [illegible] be [illegible] along the [illegible] either within [illegible] in the [illegible] zone of [illegible], the implementation of this procedure would probably not be necessary.

The implementation of a number of compressor stations would be necessary for a pipeline of this length in order to maintain high pressures, particularly at the pipeline termination point where outlet pressures need to be at an acceptable level for the liquefaction process, greater than or equal to 400 psi. High pressures are also needed to maintain high mass velocities, i.e. to operate a high gas flow rate. A simple computer programme[33] can be used to calculate the number of compressor stations needed to obtain a desired outlet pressure for a given pipeline length and inlet pressure. Let us consider the following example, which concerns a hypothetical 4000 km (1000 mm / 42 in

[32] [illegible] would not be [illegible]

[33] [illegible] used for the [illegible] pipeline [illegible]. The [illegible] are [illegible] the [illegible] length). The programme does not take into [illegible].

Figure 5.14 Schematic cross section and side view showing the thermal effects of an insulated, cold, buried pipeline with heat pipes at permafrost boundary at (a) time of installation and (b) long-term. Source: Jahns, 1984.

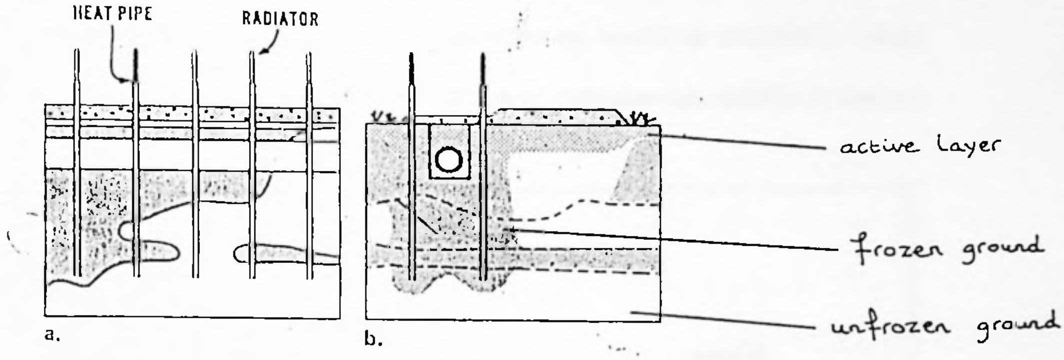
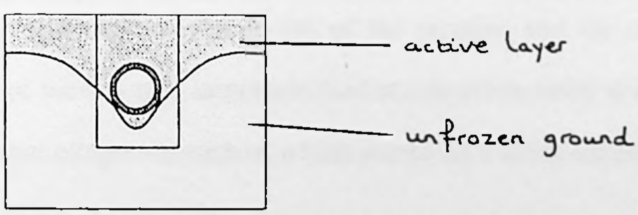


Figure 5.15 Schematic cross-section showing the effects of insulation on a cold pipeline in unfrozen soil. Jahns, 1984.



diameter) chilled (0°C) gas pipeline with a wall thickness of 12.7 mm (0.5 in) and an inlet pressure of 1088 psi. The programme tells us that the pressure will have dropped to 727 psi after 396 km (compression ratio[17] : 1.5). This means that in order to obtain an outlet pressure of 925 psi, two compressor stations will be needed at roughly 400 km intervals along the right-of-way. Fig.5.16 illustrates this falling and rising pressure over 1000 km. A trans-Sakha gas pipeline would be almost twice this length, so it is possible that at least four compressor stations would be necessary, taking into consideration the need to maintain pressures over the relatively mountainous terrain of eastern central Sakha and Khabarovsk Kray.

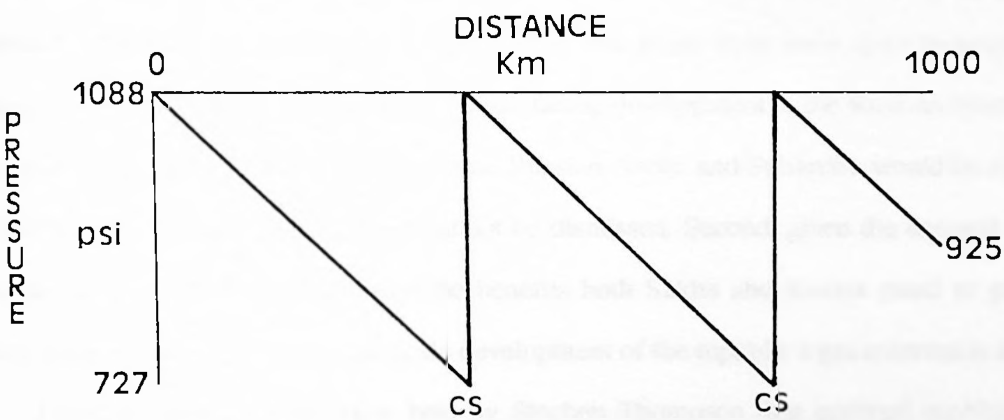


Figure 5.16 Diagram showing falling and rising pressure on a hypothetical 1000 km chilled gas pipeline with two compressor stations. Source: Hotchkiss, 1994.

CS : compressor station

Given the extremely low winter temperatures, the length of the pipeline and the desire to complete construction work by the end of winter, it is important that construction work is efficient and carried out by a relatively large number of spreads each of which works on a small section of the pipeline.

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[17]The compression ratio is calculated by dividing the inlet pressure by the outlet pressure. A normal ratio is 1.4 to 1.5.

Chapter 6

Conclusion

6.1 CONCLUSIONS REGARDING THE PLANNING, CONSTRUCTION AND OPERATION OF THE MIRNYY - SEA OF OKHOTSK COAST GAS PIPELINE.

There is little doubt that pipeline planning and construction in the Sakha Republic will be an extremely challenging task. This is quite clear given the republic's harsh climate, complex permafrost conditions and poorly developed infrastructure, not to mention the unpredictable relationship between it and the Federation. However, it is imperative that a conclusion does not paint an entirely pessimistic picture. There are two main reasons for this. First, there have been numerous studies focusing upon the problems, particularly physical, facing development in the Russian North. A study focusing on these aspects of development in the Russian Arctic and Subarctic would be repetitive to say the least, although quite clearly they cannot be dismissed. Second, given the demand for gas, in particular LNG, in the Pacific Rim and the benefits both Sakha and Russia stand to gain from a pipeline in the Russian Far East, large-scale development of the republic's gas reserves is inevitable.

I tend to agree with the view held by Stephen Thompson that political problems will lie behind major delays to pipeline development in the Sakha Republic. These are potentially more damaging than problems surrounding construction in permafrost. In fact, the delays imposed by political instability could actually benefit the geotechnicians studying these problems. The longer the delay, the more time the geotechnicians have for research.

As regards the pipeline, there are a number of advantages in following a west - east right-of-way as opposed to one oriented north - south. Above all, the construction and operation of a pipeline laid due east, towards the Sea of Okhotsk coast, stands to benefit from the environmental uniformity derived from staying within a narrow latitudinal band. In addition, the incorporation of a tanker sector makes for a supply operation less prone to political disruption (should for example the

Chapter 6

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There is little doubt that pipeline planning and construction is [illegible] extremely challenging task. This is quite clear from the Republic's harsh [illegible] conditions and poorly developed infrastructure, not [illegible] between the [illegible] Republic and the Federation. However it is my conclusion that a [illegible] is [illegible] potentially [illegible] project. There are two main reasons for this. First, there [illegible] focusing solely on problems, particularly physical, facing development in the [illegible] region [illegible] focusing on these aspects of development in the Russian Arctic and Subarctic would be instructive [illegible] as to [illegible], although quite clearly they cannot be dismissed. Second, given the demand for gas, in particular LNG, in the Pacific Rim and the benefits both Sakha and Russia stand to gain from a pipeline in the Russian Far East, large scale development of the republic's gas reserves is inevitable.

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As regards the pipeline, there are a number of advantages in following a west - east [illegible] as opposed to one oriented north - south. Above all, the construction and operation of a pipeline [illegible] the east, towards the Sea of Okhotsk coast, stands to benefit from the environmental uniformity derived from staying within a narrow latitudinal band. In addition, the incorporation of a rather [illegible] route for a supply operation [illegible] prone to political disruption (should for example the situation in the Korean Peninsula continue to deteriorate) and more amenable to fluctuations in world energy demands, especially those of Pacific Rim nations.

The west - east pipeline should experience few problems in adhering to the 'corridor concept'. This is because there are few existing corridors to choose from and of those there are a number of important ones that maintain a roughly west - east orientation. Bearing in mind the importance of this concept, the first of the two Mirnyy - Yakutsk options would seem the most suitable.

The buried pipeline alternative is clearly preferable given the safety and economic factors. Maps are useful for the initial stages of research for a buried pipeline project to determine for example soil types, active layer depths and permafrost continuity. As has been the aim here, they should be used to delineate a rough corridor whose inherent conditions might be suitable for the pipeline. But they are ineffective for determining conditions at a micro-level. Therefore, extensive research involving lengthy field trips must be carried out before any decisions can be taken regarding the final pipeline right-of-way. Such field trips would be essential in order to ascertain which areas of central Sakha contain the smallest concentrations of frost susceptible soils.

Although the risk of continuing heaving can be overcome by burying below the warmer active layer, this may not be possible everywhere. In such areas, wide expanses of sand rich soils must be sought and then used for the buried pipeline. If sandy soils are broken up by frequent silt (*suglinoks* and *supeses*) rich soils, it is best to rule out construction there and to find areas with larger expanses of silts and sands, in order to avoid multiple cases of differential heaving over short distances. In most cases differential heaving would be minor but burying in sand is most important near rivers and lakes where soil temperatures may be warmer (and thus more conducive to the heaving process) well below the normal range of depths at which pipelines are buried (ca.2 m). In respect to solifluction on river banks, it might be advisable to use the directional drilling technique incorporating a longer than normal directionally drilled section. This would eliminate the need to bury the pipeline within the bank. Areas with particularly deep active layers should be avoided at all costs in view of the danger posed by landslides.

situation in the Korean Peninsula continue to deteriorate and more amenable to fluctuations in world energy demands, especially those of Pacific Rim nations.

The east – west pipeline would experience few problems in adhering to the 'corridor concept'. This is because there are few existing corridors to choose from and of those there are a number of important ones that maintain a [illegible] and [illegible] orientation. Bearing in mind the requirements of this concept, the first of the two alternatives ([illegible] Option) would meet the same criteria.

The buried pipeline [illegible] There are [illegible] for the [illegible] [illegible] should be used to delineate a [illegible] permafrost conditions [illegible] [illegible] conditions [illegible]. Therefore, [illegible] (roughly [illegible]) would be carried out before any decisions can be taken regarding the final pipe [illegible]. Both field trips would be essential in order to determine which areas [illegible] the widest concentrations of most susceptible soils.

Although the risk of continuing heaving can be overcome by burying below the [illegible] active layer, this may not be possible everywhere. In such areas, wide expanses of land rich with [illegible] and then used for the buried pipeline. If sandy soils are broken up by frequent silt [illegible] with silts, it is best to rule out construction there and to find areas with [illegible] of silts and sands, in order to avoid multiple cases of differential heaving over short distances. In these cases differential heaving would be minor but burying in sand is most important near rivers and lakes where soil temperatures may be warmer and thaw more completely as the [illegible] well below the normal range of depths at which pipelines are buried (ca 2 m). In regard to construction on river banks, it might be advisable to use the directional drilling technique [illegible] longer than normal directionally drilled sections. This would eliminate the need to [illegible] within the bank. Areas with particularly deep active layers should be avoided at all costs in view of the danger posed by landslides.

In the lead up to construction, equipment must be delivered wherever possible by river (or sea) during the summer, and by 'winter roads' during the long winters. The extensive use of large shallow-draught vessels on the River Lena and the density of rivers suitable for 'winter road' usage indicate that these methods of delivery would be most practical. Once construction gets under way, preferably at the beginning of winter, its smooth running and efficiency is imperative to allow completion of the various sections of the pipeline before the onset of above-zero temperatures. Given the distance between Mirnyy and the Sea of Okhotsk coast, this could only be achieved by employing a large number of spreads working simultaneously on relatively small sections.

Most of the pipeline would lie within continuous permafrost and so there can be little doubt that the pipeline would be chilled. As we have seen, the problems relating to chilled pipeline interaction with 'warm' permafrost would be relatively minor in comparison to those involving discontinuous permafrost where islands of unfrozen ground are common. At the boundaries between frozen and unfrozen ground, differential heaving could cause severe pipeline distortion. This is another area that needs to be investigated in depth. There are some solutions to the problem but they are quite radical and in the case of overexcavation, not always practical.

6.2 TO WHAT EXTENT IS NATURAL GAS ENVIRONMENTALLY EXPEDIENT?

We must now attempt to show to what extent the addition of the transport stage to the utilization stage changes the overall assumption that gas is 'environmentally sound'. This new component within the equation will almost certainly have a negative effect, but the degree to which it lessens the environmental expediency of natural gas is impossible to predict. This varies from country to country and project to project. Clearly, we can only answer this part of the question once a particular project to develop gas supply systems has been completed. However, the reduction in the environmental expediency of natural gas will be similar to that observed for oil or coal, both of which require the development of extensive transport infrastructures for their delivery to markets. In the case of oil, it is almost identical to that of natural gas since pipelines are also used. We then see

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Most of the pipeline would lie within continuous permafrost [illegible] and the pipeline would be chilled [illegible] we have [illegible] permafrost would be relatively [illegible] adoption [illegible] discontinuous permafrost where [illegible] difficult [illegible] and [illegible] ground, differential [illegible] could cause severe physical damage [illegible] and this needs to be investigated in depth. There are some solutions to the problem but they [illegible] in the case of [illegible], not always practical.

9.2.3 TO WHAT EXTENT IS NATURAL GAS ENVIRONMENTALLY SUPERIOR?

We have now attempted to show to what extent the addition of the transport stage to the calculations might change the overall assumption that gas is 'environmentally sound'. This new component would in conjunction with others certainly have a negative effect, but the degree to which it lessens the environmental superiority of natural gas is impossible to predict. This varies from country to country and project to project. Clearly, we can only answer this part of the question once a particular region to develop gas supply systems has been completed. However, the reduction in the environmental superiority of natural gas will be similar to that observed for oil or coal, both of which require the development of extensive transport infrastructures for their delivery to markets. In the case of oil, it is almost identical to that of natural gas since pipelines are also used. We then see that the reduction is similar for all three resources. In other words, relative to each other, the environmental expediency has been little altered. Gas maintains the status of being more 'environmentally sound' than oil and gas.

Unfortunately, the reduction would be significant in the case of Sakha gas. Why is this so? A prevailing feature of the Circumpolar North is that the natural environment is susceptible to long-term environmental damage. This has been illustrated throughout the thesis. However, if one moves down the scale to the Russian sector of the Circumpolar North, serious complications arise. These stem from:

1) The unstable and unpredictable political and economic environment, which can have the effect of slowing down and even halting development if it goes ahead.

2) The general complications resulting from working with people who are used to doing things in entirely different ways. Something that may seem unimportant to them could be to westerners crucial for the efficient execution of the project.

3) The region's poorly developed transport infrastructure (often meaning new communications routes have to be built when new deposits are opened up).

4) The extreme physical conditions which are unparalleled elsewhere in the Circumpolar North (in Sakha's case, unparalleled elsewhere within the Russian North).

There are two further problems. First, 1), 2) and 3) are compounded in the Sakha Republic since it is an independent unit still under the influence of a separate government located 5000 km away; second, these problems have the unfortunate effect of exacerbating one another. An example of the possible consequences of these problems is as follows. The delay caused by a combination of Russian and Yakut bureaucracy and disorganization may slow down construction activities to such an extent that it is impossible to complete backfilling and to start gas transmission by the end of the winter. If the delay means that the trenches have not been backfilled, above-zero temperatures would start to melt exposed ice rich soils, causing melting and initiating the processes leading to the formation of thermokarsts.

that the reduction is similar for all these resources. In other words, relative to each other, the environmental expediency has been little altered. Gas maintains the status of being more environmentally sound than oil and gas.

Unfortunately, the reduction would be significant in the case of Sakhalin gas. Why is this so? A prevailing feature of the Circumpolar North is that the natural environment is susceptible to long-term environmental damage. This has been illustrated throughout the thesis. [illegible] there the study to the Russian sector of the Circumpolar North, [illegible] was seen.

1) The unstable and unpredictable political and economic environment, which [illegible] slowing down and destabilising development of projects in the area.

2) The general complications resulting from working with people who [illegible] in different ways. Something that may seem unimportant to us could [illegible] for the efficient realisation of the project.

3) The region's poorly developed transport infrastructure (often requiring new construction as [illegible] where no deposits are operating).

4) The extreme physical conditions which are unprecedented elsewhere in the Circumpolar North (in Sakhalin case, unprecedented elsewhere within the Russian North).

There are two further problems. First, 1), 2) and 3) are compounded in the Sakha Republic [illegible] that it is an independent unit still under the influence of a sluggish government [illegible] 2000 has long argued). Second, these problems have the unfortunate effect of exacerbating one another. An example of the possible consequences of these problems is as follows. The delay caused by a combination of Russian and Yukos bureaucracy and disorganisation may slow down construction activities to such an extent that it is impossible to complete the drilling and to start gas transportation by the end of the season. It would be known that the countries have not been benefited, short-term commitments would start to walk through on their path, causing wasting and claiming the processes leading to the expansion of resources.

This thesis has shown that there are ways of stemming the reduction in the environmental expediency of natural gas, but given the aforementioned factors, the conclusion must be that in present day Sakha, this stemming can be of a limited extent only. Therefore, the fact that pipeline construction in the Sakha Republic will not commence for a decade or more must be viewed positively. The intervening years will be vital for research not just into pipelines in permafrost, but also into important areas such as revegetation in the post-construction stage. Russia's economic and political problems should have moved some way towards being solved and the unpredictability surrounding relations between the federation and the republic should have been dispelled. In addition, foreign investment policies (concerning environment, tax, etc.) will have had time to evolve.

The issues raised in this thesis are those that should be high on the agenda of planners involved in any trans-Sakha gas pipeline project. They will have to acknowledge not only the most obvious obstacles, for example environmental constraints relating to permafrost, but also the less predictable and less clear cut obstacles namely regional Russian Far Eastern politics and relations between the nations of the Pacific Rim. Developments on the Korean peninsula will be extremely influential. There is no doubt that the seeds of such a pipeline project are slowly germinating. The aim must be to ensure that the germination and subsequent flowering of this project both advance with minimal disruption.

This thesis has shown that there are ways of stemming the reduction in the environmental expediency of natural gas, but given the aforementioned factors, the conclusion must be that in present day Sakha, this stemming can be of a limited extent only. Therefore, the fact that pipeline construction in the Sakha Republic will not commence for a decade or more must be judged positively. The intervening years will be vital for ensuring the best infrastructure is developed and also less important areas such as a resolution to the [illegible] of the [illegible]. [illegible] political problems should have moved some way towards being solved [illegible] maintaining relations between the federation and the republic [illegible] foreign investment policies (especially [illegible]) [illegible].

The issues raised in this thesis should be taken as high on the agenda of any party involved in any trans-border gas pipeline project. Care will need to be taken to [illegible] obvious obstacles, for example environmental [illegible] problematic and less clear [illegible] between the nations of the Pacific Rim. Developments on the Korean peninsula will be extremely influential. There is no doubt that the seeds of such a pipeline project are slowly germinating. The aim must be to ensure that the germination and subsequent flowering of this project both advance with minimal disruption.

Appendix 1
Selected Sakha Republic Natural Gas Statistics

NOTE : *These figures should be treated with caution. Estimates vary considerably and this goes to show how difficult it is to give accurate answers to important questions surrounding Sakha's present gas reserves. In addition, it has not always been made clear which categories reserve estimates fall into, i.e.*

A (reserves in a pool or accumulation which have been explored and studied in considerable depth).

B (reserves in an accumulation, the gas content of which was established by obtaining commercial flows of combustible gas with various choke sizes, and favourable logging data, as well as studies of core samples).

C_1 (reserves of pools or accumulations in which the gas content was established on the basis of commercial drill-stem tests of individual wells, or on the basis of favourable logging data on several other wells).

C_2 (reserves of combustible gas, the existence of which is deemed possible on the basis of favourable geological and geophysical data extrapolated to unexplored / undrilled structures, structural fault blocks and potential reservoir beds).

Definitions from Meyerhoff, 1983, p.329.

Estimated gas reserves, republic total ($A+B+C_1+C_2$):
Approximately 14 TCM.

Potential gas reserves:
107 TCM (This is the highest estimate of potential reserves found during the author's research)

Proven gas reserves (top estimates):
8 - 10.5 TCM

Dynamics of gas reserves, 1991-2011 ($A+B+C_1$) (TCM):

Reserves at 01/01/92	1991-1995 G	1991-1995 P	Reserves at 01/01/96	1996-2000 G	1996-2000 P	Reserves at 01/01/2001	2001-2005 G	2001-2005 P	Reserves at 01/01/2006	2006-2010 G	2006-2010 P	Reserves at 01/01/2011
0.9	0.20	0.01	1.11	0.20	0.01	1.31	0.20	0.02	1.49	0.28	0.02	1.75

G - growth; P - production.

Dynamics of gas reserves, 2021-2041 ($A+B+C_1$) (TCM):

Reserves at 01/01/2021	Reserves at 01/01/2031	Reserves at 01/01/2041
2.23	2.69	3.15

1992 growth in gas reserves:
60 BCM
(2nd largest growth in Russian Federation after Shtokmanovskoye field [Barents Sea] - 510 BCM)

Gas production since 1967:

Total	1986-1988/89
ca.19.4 BCM	10 BCM

Gas production, per annum:

1970	1987-88	1989-91	1992	1993 (plan)	1994 (plan)	1995 (plan)	1993-2005 (planned)	potential
0.2 BCM	1.3 BCM (each year)	1.4 BCM (each year)	1.538 BCM	1.55 BCM	1.55 BCM	1.72 BCM	to 1.8 BCM	8-14 BCM

Degree of depletion of primary resource potential (%):

By 2011	By 2041
17	35

Estimated recoverable gas reserves by region ($A+B+C_1+C_2$) at 01/01/1993:

Nepa-Botuobian	Vilyuyan	Berezovsk Depression
789 BCM	506 BCM	12 BCM

Component reserves in gas, 1993-2011 (MT):

Ethane	Propane	Butane	Sulphur	Helium	condensate
01/01/1993					
45.4	22.5	11.4	--	1485.6⌖	23.8
01/01/1996					
58.0	28.8	14.7	--	2160.9⌖	28.44
01/01/2011					
87.9	43.5	22.5	--	4052.0⌖	37.94

⌖In each case, the helium component is about one third of the Russian Federation total.

Vilyuyan Region statistics:

Discovered fields	Indicated reserves✪	Production (1992)	Current field status
Andylakhskoye	N/A	Nil	Explor. suspended due to insignificant reserves
Srednetyungskoye	1.86 TCM✸	Nil	Fully delineated, exploration completed
Nizhnevilyuyskoye	0.27 TCM✧	Nil	Explor. suspended due to insignificant reserves
Badaranskoye	0.40 TCM	Nil	Explor. suspended due to insignificant reserves
Sobolokh-Nedzhelinskoye	0.58 TCM	Nil	Fully delineated, exploration completed
Srednevilyuyskoye	2.13 TCM	1.0893 BCM○	Under commercial exploitation
Nizhnetyukyanskoye	N/A	Nil	Currently being explored/evaluated
Tolon-Mastakhskoye	1.04 TCM	262.1 MCM●	Fully delineated, exploration completed

✪Estimated recoverable reserves.
✸Proven reserves : 165.74 BCM.
✧Proven reserves : 166.7 BCM.
○(1993 plan - 1.11; 1994 plan - 1.13; 1995 plan - 1.27)
●(1993 plan - 250; 1994 plan - 230; 1995 plan - 200)

Nepa-Botuobian Region statistics:

Discovered fields	Indicated reserves✪	Production (1992)	Current field status
Vilyuy-Dzherbinkoye	Not available (N/A)	Nil	Currently being explored/evaluated
Verkhnevilyuchanskoye*	3 TCM	Nil	Fully delineated, exploration completed
Iktekhskoye	N/A	Nil	Currently being explored/evaluated
Bes-Yuryakhskoye	N/A	Nil	Currently being explored/evaluated
Tas-Yuryakhskoye*	N/A	Nil	Fully delineated, exploration completed
Srednebotuobinskoye*	1.8 TCM	162.1 MCM⊙	Fully delineated, commercial exploit. to begin
Chayandinskoye	N/A	Nil	Currently being explored/evaluated
Nizhnekhamakinskoye	N/A	Nil	Currently being explored/evaluated
Vostochno-Talakanskoye	N/A	Nil	Currently being explored/evaluated
Talakanskoye	0.55 TCM	Nil (minor oil)	Currently being explored/evaluated
Ozernoye	N/A	Nil	Currently being explored/evaluated
Tympuchikanskoye	N/A	Nil	Currently being explored/evaluated
Mirnyy	N/A	Nil	Explor. suspended due to insignificant reserves
Nelbinskoye	N/A	Nil	Currently being explored/evaluated
Severo-Nelbinskoye	N/A	24.5 MCM◎	Under test prior to commercial exploit'n
Irelyakhskoye	N/A	Minor gas production	Fully delineated, commercial exploit. to begin
Machchobskoye	N/A	Nil	Currently being explored/evaluated

✪Estimated recoverable reserves.
*Combined estimated reserves for these three fields : 400 BCM.
⊙(1993 plan - 180; 1994 plan - 190; 1995 plan - 190)
◎(1993 plan - 10; 1994 plan - 20; 1995 plan - 60)

<u>Sources:</u>

Dorian *et al. eds.*, 1993, p.362.
Intera & *Sakhaneftegaz*, 1993.
Leaver, 1992, p.63.
Pipeline & Gas Journal, 1992, p.2
Sagers, 1992, p.208.
Smith Rea & *Infoservice*, 1993, p.6.
Smith Rea & *Infoservice*, 1994, p.90, 141-148.

Appendix 2

The Tanker Section

A brief description of the tanker section will provide an impression of the supply route as it would be in its entirety.

Okhotsk and Magadan, approximately 400 km apart, are the two potential pipeline termination points on the Sea of Okhotsk where gas would be liquefied and loaded on to ice-strengthened LNG tankers. Although Magadan lies further from Yakutsk, it would probably be the first choice since it is a city (capital of Magadan Oblast') and has a large well-established port, called Nagayevo, which has operated through winters since 1962 (North, 1990, p.197). Outside the Vladivostok region, it is the only port in the Russian Far East equipped to handle ro-ro[1] freight from the SA-15 (Noril'sk Class) icebreaking multi-purpose vessels and has specialized container facilities. Little is known about the port at Okhotsk except that it is much smaller than Nagayevo. Clearly, Okhotsk's main advantage is its relative proximity to the gas fields, meaning the total pipeline length would be considerably shorter.

Important research will be needed to investigate fluctuations in sea ice conditions at both ports. Sea ice should not be a cause for concern in view of BP proposals to develop an LNG loading terminal at Kivalina on the northwest coast of Alaska. Kivalina is at latitude 68°N, whereas Magadan lies at 59.5°N and Okhotsk at 59°N. This would indicate that more favourable ice conditions at Magadan and Okhotsk can be overcome more economically since for example, tankers would be of a lower ice class than those required for Kivalina. BP is currently investigating special loading facilities designed to inhibit the formation and accumulation of sea ice in the port (Holleyoak, 1994).

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[1]Roll on - roll off.

Wind is another important factor to consider. Single Point Mooring (SPM) arrangements are preferable at ports where wind is known to be problematic since these allow the tanker to drift with the wind while loading goes ahead unimpaired.

Ice-strengthened tankers with a 60,000 ton LNG capacity would cost approximately $280 million, as opposed to $230 million for conventional types. A fleet of these would be required in order to maintain a constant flow of LNG to markets. The number of tankers needed to maintain this flow would vary according to the destination of the LNG, port turn-around times, time needed to clear port of ice[2], loading times, possibility of weather delays, and other variables. The cost of this fleet would be deferred as production and supply of LNG builds up.

Research into this sector of the supply route will need to be extensive, although it would appear that engineers already possess solutions to many of the problems surrounding LNG loading at ports prone to strong winds and difficult ice conditions. As regards the vessels, there are already ice-strengthened petroleum tankers supplying destinations in the Circumpolar North. The 26,000 dwt M.V.Arctic, owned by Canarctic, operates in the Canadian Arctic. Arctic Shipping Services, a Russian-Finnish joint venture, uses 16,500 dwt Lunni-class tankers in the Russian Arctic. In 1993, one such vessel made three voyages along the Northern Sea Route between Arkhangel'sk and the Yana delta on the Sakha Republic's north coast, a distance of 4000 km (Herring, 1993, p.16). The vessel did require the assistance of a nuclear-powered icebreaker for a 300 km section around the notoriously icy Taymyr Peninsula. The M.V.Arctic and the Lunni-class tankers have double hulls. Both Canarctic and Neste Oy (which jointly owns Arctic Shipping Services) have made environmental safety the top priority for their Arctic tankers operations.

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[2]In the worst ice conditions, icebreakers would be needed to improve access to the port.

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