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ENVIRONMENTAL HERITAGE OF OIL SHALE MINING

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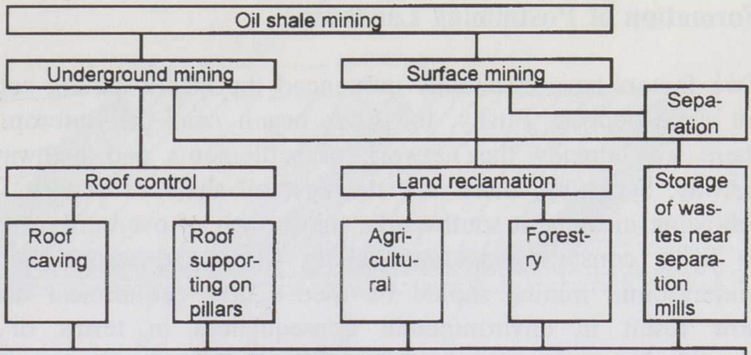
Oil shale mining like every kind of exploitation of mineral resources imparts a variety of impacts on the environment. One group of factors has a temporary impact during the mining activities only, another group of factors leaves its footprints in nature for a long time. Geological conditions, mining methods - underground or surface mining, roof control methods and methods of reclamation determine the variety of landforms and their parameters in postmining landscape.

Long-time ecological observations and changing economical conditions can influence the current attitudes and criteria of assessments of the environmental impact caused by mining.

Introduction

For eight decades oil shale as a mineral resource has provided the local economy and neighbouring areas with power, supporting the social and cultural life here. One part of mining activities firmly stays "at home", the impact of mining on environment. Despite of land reclamation and another postmining improvements, changes are remarkable and they will stay. There is another question - whether these changes are always negative, and how we can adapt to changes. Some criteria used to assess the impact have changed during the last decades and our criteria will probably change during the next thirty years to assess the results of today's activities. The problem may be better solved using the experience of these countries where mining was developed centuries ago, e.g. of the area where the industrial revolution of Europe started.

A part of environmental impact disappears together with mining, generally called nuisance factors - noise, vibration, dust, etc. A permanent environmental heritage of mining is the postmining landscape, including the structure of rocks, their geotechnic state, relief elements and water regime, i.e. the new, technogenic morphology [1].



Results in the landscape					
1. Ground structure	Natural, deformed, stabile	Natural, undeformed, unstabile	Orderly artificial		Artificial; limestone with oil shale residues
2. Micro-relief	Wavy, depressions	Generally smooth, spontaneous subsidences	Plateaus between trenches	Wavy plateaus between trenches	Waste heaps and plateaus
3. Relief elements, height/ /depth, m lenght, m width, m	0.7 - 1.0 500 - 600 100 - 300	1.2 - 1.5 50 - 600 50 - 300	10 - 30 >2000 ~1000	10 - 30 >2000 ~1000	15 - 55 - 130 - 360
4. Area of occurence, km^2	130	100 (2.5% subsided)	1.5	93	3.4
5. Environmental impact	Erosion, submerged depressions		-	-	Danger of spontaneous combustion
6. Availability	Agriculture and forestry (after reclamation)		Arable lands, grasslands	Forestry, recreation areas	-

Fig. 1. Formation of postmining landscape

Formation of Postmining Landscape

Two factors have essentially influenced the whole mining activity in the oil shale deposit. Firstly, the work began near the outcrop line where there was already the network of settlements and highways, as well railway. Secondly, there was the best oil shale of deposit. During the following movement southwards, the growth of overburden made miners to make constantly decisions about when and where the surface or underground mining should be used. These economical decisions will now result in environmental consequences in terms of landscape. Considering underground mining (Fig. 1) it is easy to comprehend that mining methods and roof control methods in particular will determine the following state of postmining solid environment. Roof control methods and parameters determine the formed relief character and size of elements, the stability or instability of basic rocks forming this landscape. Surface mining with his variety of methods is to be treated together with following reclamation. Chosen purpose of reclamation is the main factor, determining the following state of landscape (Fig. 1).

Roof control methods in underground mining and reclamation methods in surface mining determine the changes in solid environment. We can observe and measure the changes that took place yesterday and even predict with some precision the changes coming in the future. Changes in the solid environment cause changes in the liquid environment. Changes of surface water regime entail changes in plant community. After closing of mines and open casts, groundwater level will probably rise again in the area of depression. The character of restoration and its possible impacts are still unclear.

Variety of Landforms

Surface mining started from the outcrop line of the oil shale bed with removing Quaternary sediments and a thin layer of overburden only. Today the thickness of removed overburden reaches up to 20 m. A new artificial structure of rocks with a new relief (Fig. 2) is formed (height up to 10-18 m and slopes up to 40 degrees). About 115 km^2 of territory is formed in such way. These relief and structure serve no purpose today and they are classified as being only temporary before land reclamation. A small part of this territory should be preserved as a record of human activities.

The following reclamation of the surface of mined lands forms a permanent and real basis for a postmining landscape. About 80 % of mined areas have been reclaimed - 93 km^2. Two open casts (*Sirgala* and *Narva*) have reclaimed these areas as forestlands, one open cast (*Aidu*) as

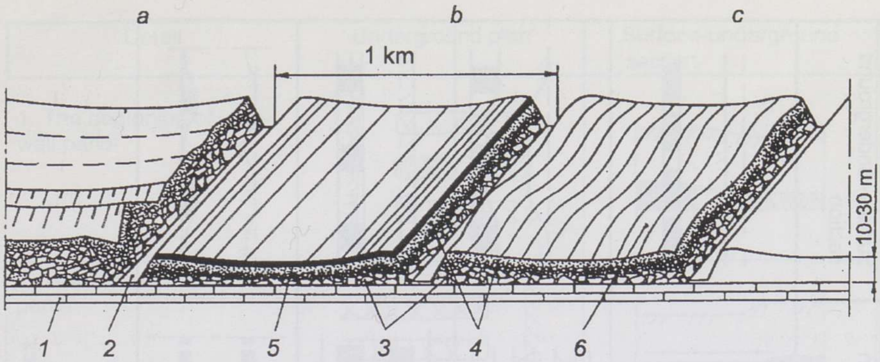


Fig. 2. New microrelief after surface mining: *1* - undisturbed bedrock, *2* - trench, *3* - removed bedrock, *4* - replaced subsoil, *5* - topsoil cover on reclaimed agricultural land, *6* - relief of reclaimed forestland

forestlands and arable (agricultural) lands as well. The "idealized" relief of areas reclaimed as arable is shown in Fig. 2*b*, where the slightly depressed area (plateau) is located between the trenches and will remain in the landscape. After the closing of the open cast, those trenches will be partially filled with groundwater. Water logging in the central part of the depressions is possible.

Most of the surface-mining area is located in woodlands and has been subsequently rehabilitated as such. The microrelief of restored areas is wavier (Fig. 2*c*) due to overburden heaps, which have been graded only partially after mining. This circumstance depends on the standard of reclamation - the permitted angle for relief slopes in the future forestlands is up to 8 degrees, in arable lands up to 3 degrees only.

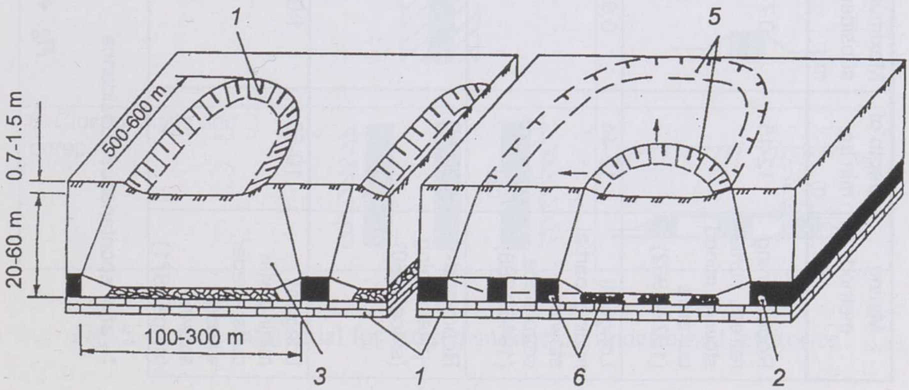
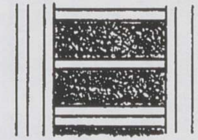
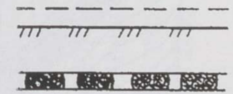
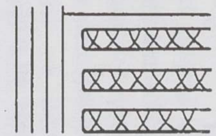
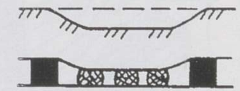
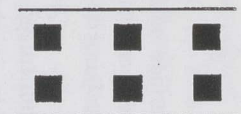
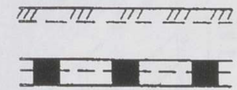
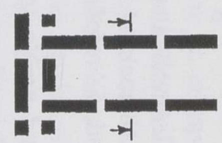
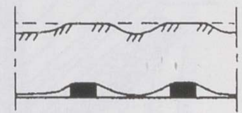


Fig. 3. Formation of subsidence troughs after underground mining: *1* - undisturbed bedrock, *2* - oil shale layer, *3* - caved overburden, *4* - trough (depression) on ground surface after mining with roof caving, *5* - trough caused by spontaneous collapse of pillars after room-and-pillar mining, *6* - pillars

Mining method	Depth of mining, m	Maximum subsidence, m	Angle of slopes, degree	Losses in deposit		Underground plan	Surface- underground section
				%	GWh/ha		
Room mining retreat, partial stowing mined out area (1922-1962)	12-15	0.7	2-3	26	20		
Longwall mining, partial stowing, coupleface (1946-1988)	12-44	0.9	2-4	24	16		
Room-and- -pillar mining (since 1960)	20-60	1.5*	4-6*	22	17		
Longwall mining with cutter-loader, without stowing (since 1971)	10-55	1.0	4-7	46	33		

* - after spontaneous subsidence

Fig. 4. Mining methods and the state of undermined territories

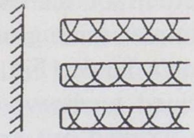
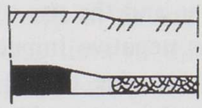
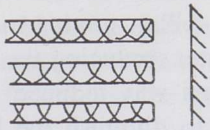
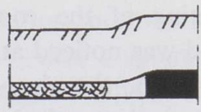
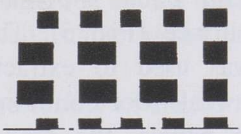
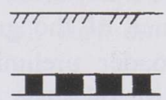
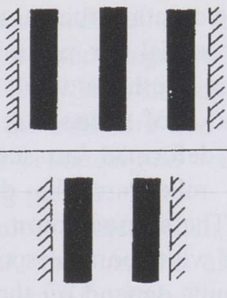
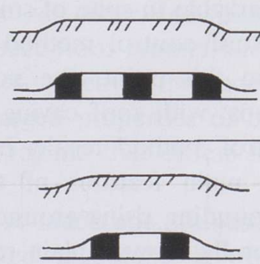
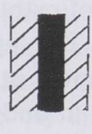
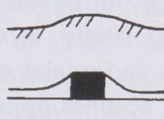
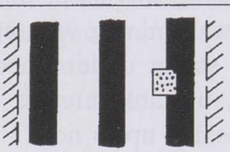
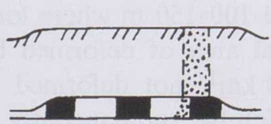
Detail	Underground plan	Surface-underground section
1. The beginning of longwall panel		
2. The end of longwall panel		
3. Entries in goaf after room-and-pillar mining		
4. Abandoned entries with chain pillars		
5. Chain pillars in goaf		
6. Closed shafts and borepits		

Fig. 5. Details substantial for ground surface on undermined territories

Underground mining produces a big variety of new visual and hidden forms in landscape. Ground surface deformations are as old as the underground mining. Small extent of oil shale mining during the first decades and the use of room-retreat mining method with stowing avoided serious negative impact on usable lands (Fig. 3). Long-wall mining with partial stowing of the undermined territory, where relief became wavier due to the entry pillars, left a worked-out area. Stowing diminished the ground surface subsidence to 0.9 m (from possible 1.4 m). In the beginning of the room-and-pillar mining no negative impact on the ground was noticed at all. Later (reducing the losses of mineable oil shale in deposit), the size of pillars was reduced so that they worked for a certain period only in order to diminish the losses of mineable oil shale in deposit. Later the collapse of pillars is possible, causing a spontaneous subsidence of the ground surface (Fig. 3). The long-wall mining with cutter-loader preliminary was used to extract the lower part of the productive oil shale bed in weak roof conditions. Without stowing goaf and leaving pillars between panels, the ground surface subsidence is remarkable in spite of small extraction thickness (Fig. 4).

Roof control method is crucial for postmined ground surface state. From this point, the mining methods used may be divided into two groups: with roof caving and roof supporting on pillars. The first, roof control method results in a deformed but stabile and wavy microrelief. The main features of this relief are the depressions - troughs and surrounding rising grounds. The second, room-and-pillar-mining method generally forms a plain relief with sporadic spontaneous depressions. The measurements of relief elements depend on the depth of mining, the size of mined out panels, the thickness of extracted bed and the parameters of stowing, where it was used [2]. The approximate depth of subsided troughs and angles of slopes are shown in Fig. 4. The ordinary length of troughs reaches approximately 600 m and width 200-300 m where long-wall mining with partial stowing was used, and, correspondingly, 600 m and 100-150 m where long-wall mining with cutter-loader was used. The total area of deformed but stable undermined ground surface is about 130 km^2, not deformed but unstable area is about 100 km^2, 2.5 % of which has spontaneously subsided up to now.

In areas, where a more sophisticated land use on postmined area is needed (buildings, ways, etc), some underground details, substantial for ground surface state, should be taken into account (Fig. 5).

In the case of long-wall mining with partial stowing, the lines of the beginning and at the end of panel on the ground surface level are important. After the start of working face (Fig. 5,*1*), on the ground surface there formed a depression above stowed goaf, and rising ground remained on pillars. Basic rocks above the depression weakened (additional joints); consequently the basement conditions and water permeability properties changed. In the end of long-wall panel (Fig. 5,*2*), the basic rocks remained in the same state and so a long-term local surface subsidence is possible there. It is probable when after stopping the face the console of roof rocks is shorter as a usual step of caving. After some period under the load of overburden, the fatigue limit of this short console will be over past and cause a local spontaneous subsidence. This moment is unpredictable but should be taken into account when planning the location of objects on the land surface.

Entries formed between bigger pillars in goaf after room-and-pillar mining are also potential inductors of deformations. After a spontaneous collapse of room pillars of lesser size the rising ground forms above the entry pillars (Fig. 5,*3*).

Where after mining with roof caving methods the entry pillars were not extracted, the relatively stable rising ground will stay on ground surface (Fig. 5,*4* and *5*).

In shallow mines a large variety of shafts, borepits and wells were used for winding, ventilation and power supply. Poor sealing of such vertical or inclined workings in jointed sedimentary rocks may cause unfavourable hydrological processes and a direct negative impact from ground surface to basic rocks (Fig. 5,*6*). The whole mining activity leaves its traces in postmining landscape: on the structure and changed properties of basic rocks, new landscape relief elements and water regime that differs from the natural of the premining period.

Surface mining causes more radical changes in landscape, (landscape restoration is more radical, too) as the changed landscape is wholly "visible and firm". The impact of underground mining is not so radical, the changes will continue for a long time after mining, and the reasons of changes are concealed in invisible underground. Due to shallow location of mine workings, even insignificant underground movements may have an effect on the ground surface. At the same time shallow mines permit better to "copy" the action of underground causes on the ground surface and better predict potential dangers.

Discussion

The Mining Act of 1927 already provided the compensation to landowners for any kind of land disturbance caused by mining. It was valid up to 1940.

The "moonscape" left by **surface mining** in post-war decades was the first serious point making miners to do something better. The reclamation of excavated overburden started in sixties. Since then the method has been perfected and the requirements of land-users, too. As a compromise between both sides, the detailed regulation of reclamation was issued in

1985. The main idea was to reclaim the spoiled area establishing detailed requirements to structure and relief of reclaimed land. According to this regulation, the "making" of arable lands was ten times more expensive than that of forestlands, and there arose some additional problems with land quality [3]. The following regulation in 1995 pointed out the possibility to establish postmining expedient land use in the mining permit. Up to now there are no cases of changing the land use after reclamation. The reclamation of forestlands to arable is unlikely; opposite cases are more plausible. After reclamation of forestlands with various kind of trees [4], variable relief, plateaus and trenches and probably arising water bodies after closing the opencast's water pumping systems enable to vary the land use (recreation, hunting, fishing). The relief formed up to now (Fig. 6) will permit to plan it for the nearest future.

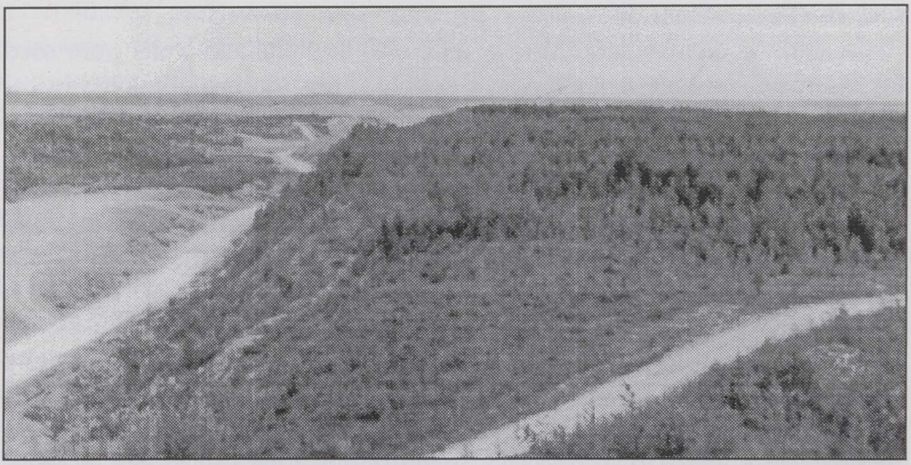


Fig. 6. Graded and reforested plateaus with a trench between them in *Aidu* opencast

In the beginning of **underground mining**, the subsidence of the ground surface followed shortly after first panels when the room-retreat method was used. Small area and stoping of goaf diminished the subsidence depth. There also remained no rising grounds between panels; territory became deformed, but relatively smooth.

Long-wall double-face method added another detail, a chain pillar between double-face panels, causing the rising grounds as surrounding borders for depressions (troughs) above the goaf. The subsidence depth grew a little. One kind of long-wall method is still in use today - that with cutter-loader, but without stowing the goaf. Due to small thickness of bed extraction, the total subsidence grew a little in comparison with previous methods, correspondingly from 0.7 and 0.9 to 1.0 m. Chain pillars left in goaf between panels also cause rising grounds.

Fig. 7. Submerged forestland in the first years after ground surface subsidence

Fig. 8. Submerged depression twenty years after the first subsidence with new plant community on the shore of an artificial forest lake

When room-and-pillar mining was taken into use there were initially no problems with ground surface depressions. Reserve strength of supporting pillars was sufficient, but the losses of oil shale in deposit rose. The optimization of losses and the strength of pillars for a certain period left the possibility of their later collapse under the load of overburden [5].

The variety of properties of rocks in pillars and sizes of pillars due to their formation with blasting method cause a subsequent uncertainty in predicting the time and place of possible collapse of pillars and, consequently, the subsidence of the ground surface. Overburden rocks subside on the residual crushed rocks of pillars, and the total subsidence is usually about 1.5 m, with an angle of slopes 6-7 degrees and sometimes up to 10 degrees. The disturbing factors are the same as in the case of long-wall mining, but more severe on a smaller area, leaving the whole area in an uncertain state. Any kind of activities on these lands should be planned according to the concrete circumstances of this activity. The preliminary positive environmental attitude to this mining method has changed by now.

The soil erosion on arable lands rises remarkably if the angle of slopes exceeds three degrees. Looking at Fig. 4, one can see that only the eldest mining method did not exceed this number. Intensive soil ploughing causes the mottled character of thin topsoil and it in turn influences the harvest there. On grasslands and forestlands the erosion factor on the slopes of depressions is not essential.

The subsoil is formed by Quaternary sediments, mainly sand and moraine with a thickness varying from 0 to 10 metres. Where the subsoil thickness exceeds 2 m, the probability to find waterproof clay intercalations is very high. On lower areas (usually on forestlands after ground surface depressions), the danger of water logging of soils in the bottom of depressions arises due to the accumulation of surface (rain) water there. Over 50 % of underground mining area are covered with subsoil, where its thickness exceeds 2 metres the area needs a special surface water treatment. Detailed maps of Quaternary subsoil structure and thickness will help to predict the danger of water logging and to plan the methods of drainage. Regarding the spontaneous character of subsidences after room-and-pillar mining, there are still no satisfying measures against water logging there.

Submerged depressions have ruined plant communities and destroyed the forest in these areas (Fig. 7). These were the most negative cases of underground mining environmental impact. Some of these depressions have stayed submerged during the last twenty years, by now new plant communities have formed, close to natural one of forest lakes, and the general landscape seems fairly natural, too (Fig. 8).

It may be interesting to make sure whether the redistribution of surface water causing the losses in timber growth in depressions, favours the same process on another areas. While speaking about energy losses, one should keep in mind the resources of both - timber and oil shale. According to an analysis [6], the abatement of losses in deposit is significant, in comparison with possible timber growth on this territory (Fig. 9). In this case, the ecological and economical reassessment of the heaviest impact becomes possible.

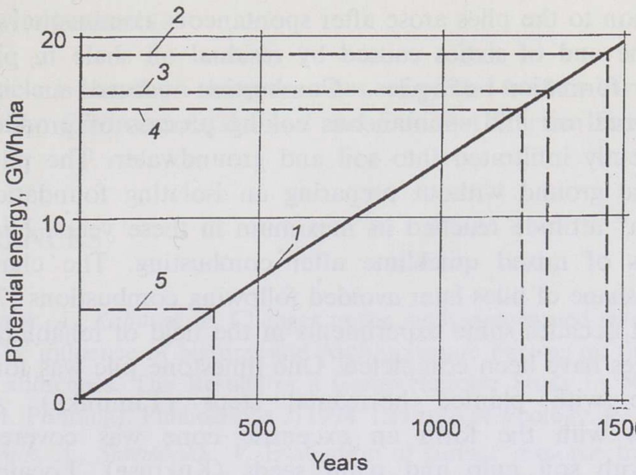


Fig. 9. Potential energy losses in mining and renewable timber production: *1* - annual growth of renewable biomass (timber) energy (0.013 Gwh/ha), *2* - losses by room retreat mining, *3* - losses by room-and-pillar mining, *4* - losses by long-wall mining with partial stowing, *5* - losses by probable long-wall mining without pillars

The water permeability of basic rocks on undermined areas in the depth of 10-60 metres is increased; the highest permeability is on the depth of extracted oil shale bed (Fig. 3). Abandoned mine workings in goaf operate as water tunnels. The horizontal permeability of pillars left between mines locally diminishes the horizontal water propagation velocity. The stowing belts and pillars left in goaf are permanently under the impact of underground in addition to water-flow. How does it influence the compaction or dispersion of stowing material and the rocks of pillars, still remains unclear. Consequently, the possible following deformations due to these factors are unclear, too.

Any kind of ground surface can penetrate directly into groundwater due to vertical joints, where subsoil does not contain the protective clay intercalations, i.e. where the thickness does not exceed 2 metres or where the subsoil structure is disturbed. Therefore the undermined areas are sensible to ground movements, surface and groundwater conditions and groundwater pollution for a long time after mining.

One of oil shale mining by-products is limestone waste. In the deposit oil shale bed contains limestone interlayers. To prepare a trade product of oil shale, the separation of limestone from mined rock in special mills is necessary. As a result there are 32 waste piles near oil shale separation mills, which consist mainly of 82-94 % limestone and 6-18 % residual oil shale. These piles have the form of truncated cones or plateaus up to 55 m high; their top view is drop-shaped or circular with a diameter of 130-360 m. The total area of those piles equals about 3.5 km^2.

The attention to the piles arose after spontaneous combustion of some of them in the end of sixties caused by residual oil shale in piles and inconsiderate formation of piles. Combustion caused an intensive pollution of local air and spontaneous coking process of produced oils that were directly infiltrated into soil and groundwater. The piles were located on the ground without preparing an isolating foundation. The "antimountain" attitude reached its maximum in these years. Nine piles became heaps of mixed quicklime after combusting. The changes in structure and shape of piles later avoided following combustions [7].

During last decades some experiments in the field of rehabilitation of solid waste piles have been completed. One limestone pile was formed in terrace shape with planted horizontal steps (Tammiku). Another limestone pile with the form an excentric cone was covered after combustion with soil pulp and plant seeds (Kukruse). Located near highway, it is now often visited by tourists as a viewing place. On the unburned piles the air isolating cover needs continuous attention in order to prevent the possible access of air to the inner body of the pile. Separated limestone is generally not weatherproof. As an organic component containing residual oil shale it is considered a poor construction material today. Obviously, these piles will stay for a long time making the Northeast Estonian plateau expressive.

Conclusions

Eighty years of oil shale mining means:

- Moving from preliminary primitive surface mining near the outcrop line of oil shale bed to fairly sophisticated and mechanized mining up to the depth of 20 metres, removing and disturbing the whole overburden with following reclamation of the whole mined-out area.
- Moving from preliminary underground shallow mining within a small area with backfill works to developed and mechanized mining with partial disturbing of landscape and the basic rocks up to the depth of 60 metres without following reclamation works on landscape.
- Increasing environmental impact per mined-out product unit because of the growth of the depth of disturbed overburden and the decreasing quality of oil shale at the same time.
- Changes of environmental attitudes and assessments during the mining period; foreseeing the changes in landscape and adaptation of following land use to these changes without increasing the expenditures for postmining reclamation proportionally to the total growth of disturbance. A man-made landscape is forming today, and it is necessary to control this process considering the demands of land use tomorrow.

Acknowledgements

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REFERENCES

1. *Toomik, A., Kaljuvee, E.* Changes in the landscape caused by oil shale mining // The influence of Natural and Anthropogenic Factors on the Development of Landscapes. The Results of a Comprehensive Study in NE Estonia (Ed. J.-M. Punning). Publications 2/1994. Institute of Ecology. P. 150-160.
2. *Toomik, A., Shtembakh, V.* Evaluation of surface response to roof caving in oil shale mines // Oil Shale. 1984. V. 1, No 3. P. 243-250 [in Russian with English summary].
3. *Leedu, E.* Agricultural recultivation of oil shale opencasts // Production and Environment. Tallinn–Kohtla-Järve, 1990. P. 29-33 [in Estonian].
4. *Kaar, E., Raid, L.* Problems in oil shale opencasts reclamation // Ibid. P. 26-29 [in Estonian].
5. *Toomik, A.* The problem of ground surface stability on oil-shale mining area // Land and Soil Protection. Ecological and Economic Consequences (Ed. E. Nugis). Proc. of Intr-Symposium. Tallinn, 6-12 June 1994. P. 124-131.
6. *Toomik, A., Samlan, Ü., Kaljuvee, E.* The development of oil shale mining and the state of the land surface // Energy, Environment and Natural Resources Management in the Baltic Sea Region (Eds Ü. Mander, J. Fenger, T. Oja, M. Mikk). 4th Intern. Confer. on System Analysis. Tallinn, May 18-21, 1993. Nordiske Seminar - og Arbejdsrapporter 1993 : 653. P. 105-114.
7. *Parakhonsky, E. V., Saranchouk, V. I.* Elaboration and introduction of fire-safety parameters of limestone piles in oil shale mines // Ugol (Coal). 1990. No 9. P. 30-32 [in Russian].

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