

# Degradation of land due to coal mining and its natural recovery pattern

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Extensive coal mining in the hill state of Meghalaya, north-east India has resulted in ecological upheaval of thousands of hectares of land. The land which is directly hit by mining operations like excavation and dumping of overburden and coal is converted into new habitats, called colliery spoils, which lack completely the soil structure and whose elemental concentrations are greatly altered. The areas like hilltops, hillslopes and cultivated and abandoned agricultural fields, which are not directly hit by mining operations, though retaining their structure, are affected by deposition of coal particles through wind and seepage water. Both physical and chemical properties of colliery spoil showed a returning trend to the characteristic pre-mined levels of the soil during 20 years of natural recovery. However, the nutrient levels were still either significantly ( $P < 0.05$ ) less (N, P, K, Mg and pH) or more (Ca, Mn, Zn, Fe and S) in the 20-year spoil compared to the pre-mined overburden soil.

It is suggested that backfilling of the pits would be a cost-effective technique to maintain the approximate original contour. Properly planned channelization of seepage water is necessary to stop the deterioration of soil quality in agricultural fields and low-lying marginal lands. This would not only restore the nutrient level but also the vegetation cover on coal-mining-affected lands.

THE state of Meghalaya, which is a union of three hill territories, namely, Garo, Khasi and Jaintia, has deposits of 560 million tonnes of coal distributed over 20 coalfields and covering an area of about 285 km<sup>2</sup> (Table 1). The coal seam lies just 3–8 m down on the bedding planes of the host rock (Figure 1). Currently, coal mining is intense in almost all coalfields in Jaintia hills, and in Cherrapunji and Laitryngew in Khasi hills. In Garo hills, with approximately 64% of the coal reserve in the state, mining has been very scanty. Though coal mining has been a part of socio-cultural life of the tribes, it is only during the last two decades that extraction of coal has developed into a commercial activity. The annual extraction rate has gone up by about 44-fold between 1970 (39,000 tonnes) and 1989

Table 1. Estimated coal reserves and area covered in three hill territories in Meghalaya

Territory/site	Reserve (million tonnes)	Area (km <sup>2</sup> )
<b>Khasi hills</b>		
Cherrapunji	19.0	36.0
East Darrangiri	31.5	21.0
Laitduh	0.12	0.12
Laitryngew	2.3	31.0
Langrin	97.61	58.38
Lundidom	0.2	0.2
Mawbehlar	0.12	0.1
Mawlong–Shella–Ishamati	12.9	8.0
Mawsynram	0.32	0.19
Pynursla–Lyngkyrdem	0.5	2.0
<b>Garo hills</b>		
Pendengru–Balphakram	107	13
Selsela	RNE	RNE
Siju	125	11
West Darrangiri	127	47
<b>Jaintia hills</b>		
Bapung	33.66	46.0
Ioksi	1.24	3.6
Jarain	1.1	2.8
Lakadong	1.5	3.0
Musiang Lamare	1.1	2.31
Sutnga	0.65	0.16

Data source: Directorate of Mineral Resources, Meghalaya.

RNE, recorded but not estimated

(170,000 tonnes). Thus, environmental degradation associated with coal extraction is a moderately recent phenomenon in Meghalaya.

Coal is extracted by 'rat-hole mining', which involves felling of trees in an area of about 200–300 m radius, digging a pit of about 20–50 m<sup>2</sup> till the coal seam is reached, clearing of seepage water accumulated in the pit, and finally extraction of coal by forming parallel galleries along the seam at a short distance from each other and propping the roof wherever necessary (Figure 2). Rat-hole mining is very successful in these hills due to proximity of coal seam to the ground. Further, it is cost-effective as it does not require any modern technology and trained manpower. From the

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**Figure 1.** A freshly opened pit of about 25 m<sup>2</sup> area.



**Figure 2.** A soil profile indicating the position and thickness of coal seam. Note the proximity of coal seam to the ground surface.

viewpoint of land degradation also, the method seems to be fairly appropriate as it directly damages only the soil structure of a small area equivalent to the size of the pit, spoil and coal heaps (Figure 3); the rest of the area retains its structure.



**Figure 3.** A colliery spoil, the habitat created consequent to coal extraction, left off for recovery but without any effort made for its revegetation. Note the contamination of coal particles and highly gravelly nature of the substratum.

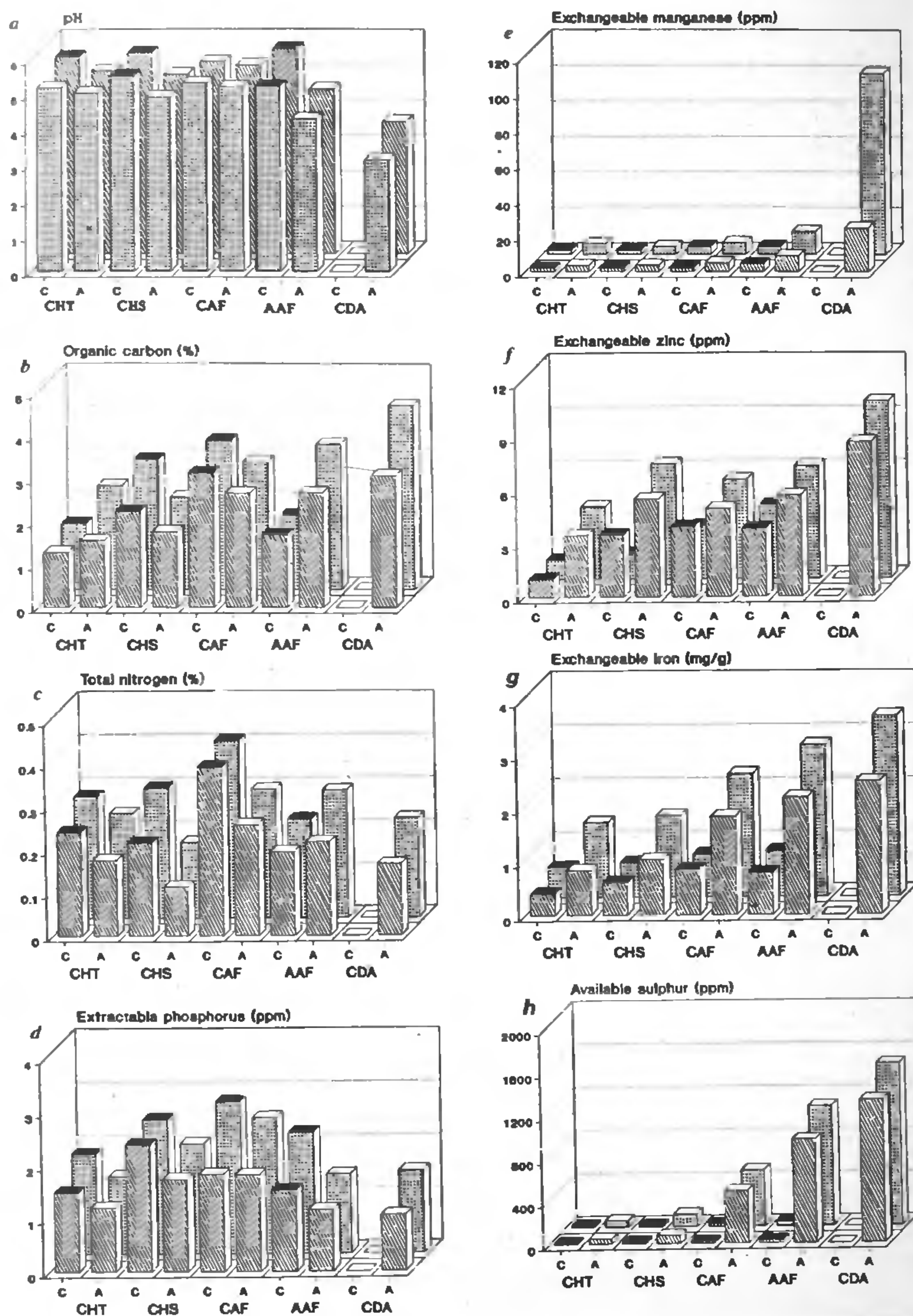
In spite of practical success and lower operating cost, there are at least two major problems associated with rat-hole mining: (i) formation of new habitats, called colliery spoils, which lack structure because of up-side-down change in the position of soil horizons and haphazard mixing of coal particles; (ii) deposition of coal particles both in wet season (through water seepage) and dry season (through wind) on the land which is not directly hit by mining operation, like hill-tops, hillslopes, abandoned and cultivated agricultural fields, and coal-dumping areas.

In the present investigation we aim (i) to assess the chemical characteristics of soil under different land use in unmined (control) and mine-affected areas to quantify the impact of coal mining on soil fertility, and (ii) to determine the physical and chemical characteristics of a native forest soil, a pre-mined overburden and an age series of colliery spoils that would help predict the natural pattern of nutrient recovery in spoils with progression in time.

### Study area and climate

The study includes three sites: Thadlaskein, Sutnga and Bapung, all exhibiting markedly similar phytogeographic features and located between 1100 and 1400 m altitude in Jaintia hills. In Bapung and Sutnga, coal extraction is at a much higher rate than in any other part of the territory. The site Thadlaskein, which is about 35 km from Bapung and 55 km from Sutnga, is not affected by coal mining and thus was considered as control. For the land degradation study samples from all the three sites were collected, whereas for the nutrient recovery study samples were taken from Bapung only, in addition to a relic forest at Mawphlang





**Figure 4.** Chemical profiles of soils from different microsites in control (C) and coal-mining-affected areas (A). CHT, cleared hill top; CHS, cleared hill slope; CAF, cultivated agricultural fields, AAF, abandoned agricultural fields; CDA, coal-dumping areas. Dot-filled bars for 0-10 cm and hatched bars for 10-20 cm depth. A bar with black top indicates statistically significant difference ( $P < 0.05$ ) with the adjacent open-top bar that belongs to the same microsite and the same depth.



in Khasi hills – which represents the highest status of forest growth attained in this region<sup>1</sup> – to serve as a reference climax plot.

Although the overall climate in the state is humid (relative humidity 60–100%), the rainfall is highly variable depending upon topographic situation and subject to interyearly fluctuations. The average annual rainfall may range from as low as 2000 mm at a low-altitude site (Burnihat, 100 m) to as high as 12,500 mm at Cherrapunji (1300 m). At Cherrapunji, the rainfall may vary between 6830 mm (in 1978) and 24,600 mm (in 1974). The average annual rainfall at Jowai, the nearest meteorological station to the study sites, is about 3613 mm. The wet season lasts for about seven months, generally beginning in April and ending in October. The average maximum and minimum temperatures are 23.7°C and 14.9°C, respectively. The granitic and gneissic soils in this range of rainfall are friable and most vulnerable to the soil erosion and nutrient depletion by the outflowing water<sup>2</sup>.

## Methods

### Sampling procedure

For land degradation study, five microsites were identified at each site, namely, cleared hilltops (CHT), cleared hillslopes (CHS), cultivated agricultural fields (CAF), abandoned agricultural fields (AAF) and coal-dumping areas (CDA). CDA were absent in the control area. Soil samples from two replicates of each microsite in control area (Thadlaskein) and eight replicates of each microsite in the affected area (four replicates in Bapung and four in Sutnga) were collected from 0–10 cm and 10–20 cm depths in September–October, 1991. All the samples were analysed for pH, organic carbon, total nitrogen, extractable phosphorus, exchangeable manganese, exchangeable iron, exchangeable zinc and available sulphur.

For nutrient recovery study, a pre-mined overburden site and mine spoils of an age series, viz. 1, 2, 4, 8, 12, 16 and 20 year, were identified in Bapung area, and a reference native forest was identified at Mawphlang. Soil samples from each of these sites were collected in three replicates at 0–10 and 10–20 cm depths during February–March, 1992. The age of the mine spoils (till 8 years) was ascertained from local miners who have been involved in this enterprise for the past 8–10 years. Age of mines greater than 8 years was arrived at by indirect estimates of the vegetation growth and corroboration with one or two veteran mine operator(s). These samples were analysed for the physical and chemical properties indicated in Figures 4–6.

### Chemical analyses

Gravels (particles > 2 mm size) were separated from the soil by passing the substratum through a 2 mm

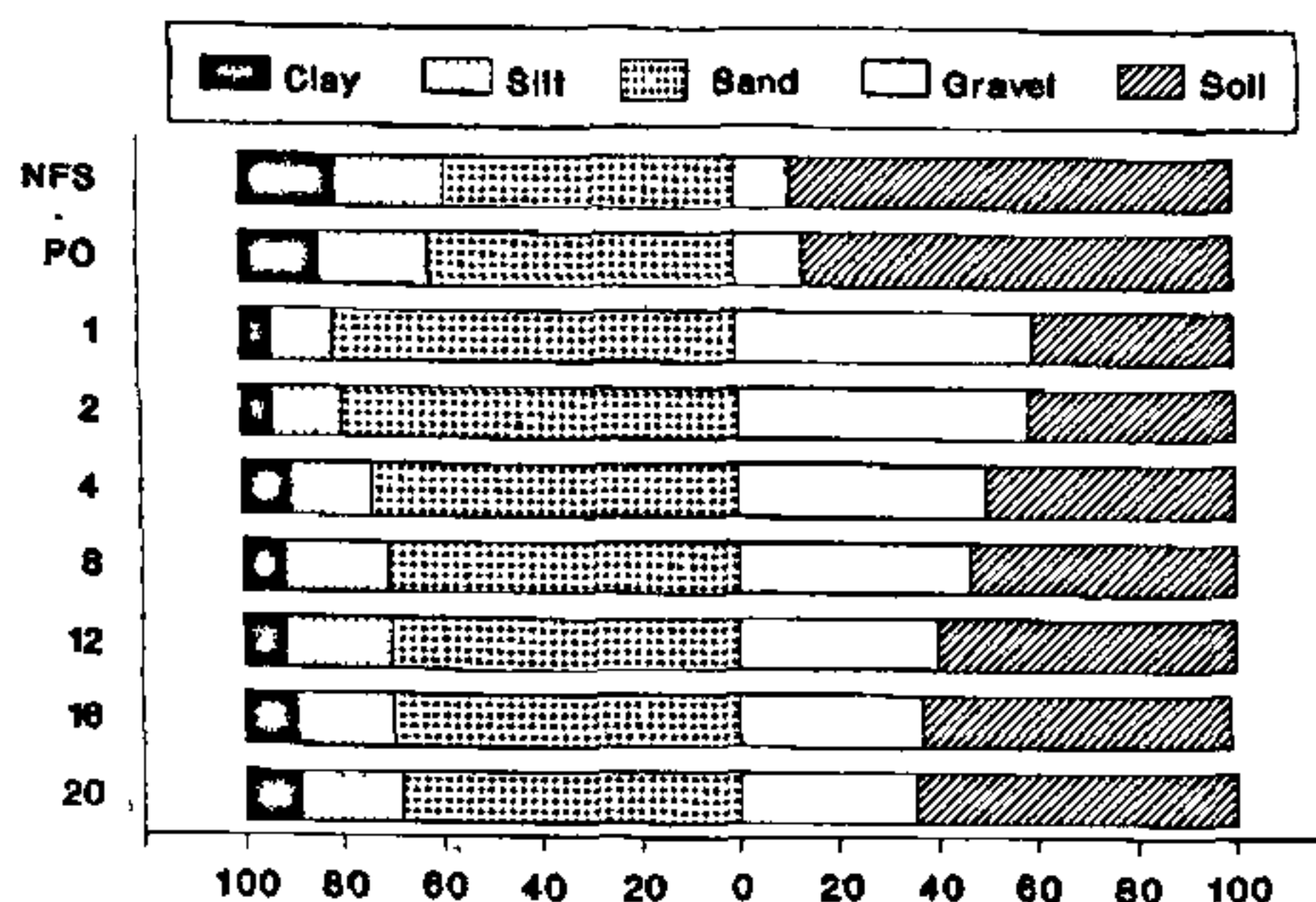


Figure 5. Mechanical analysis of colliery spoils across development sequence. First, the total substratum was categorized into gravel (particles > 2 mm in size) and soil (particles ≤ 2 mm in size) by the sieving method and each represented on per cent basis. Second, the soil fraction was classified into sand, silt and clay (texture analysis) by hydrometer method and each represented on per cent basis. NFS, native forest soil; PO, pre-mined overburden.

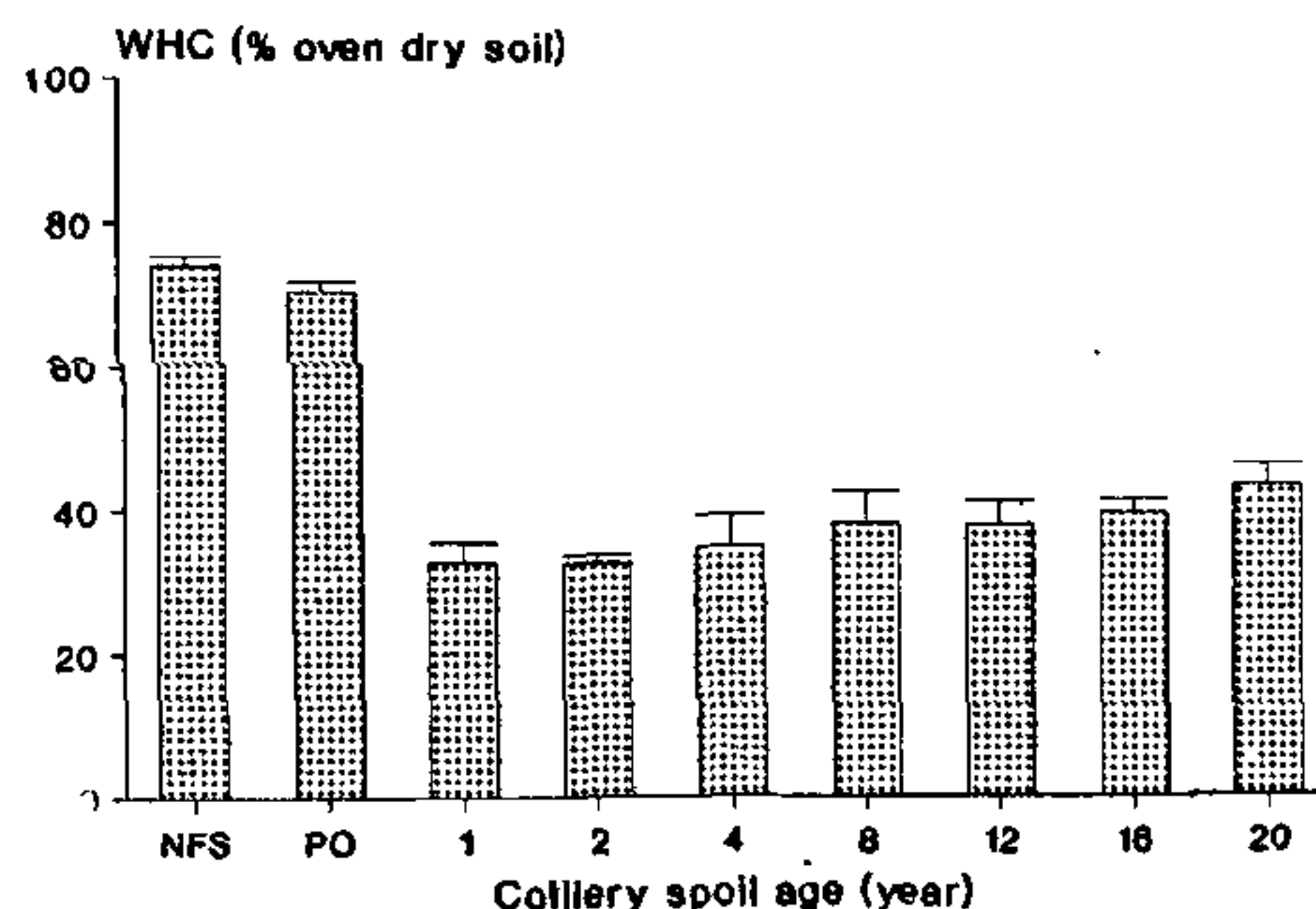


Figure 6. The water-holding capacity of colliery spoils across development sequence (represented on per cent oven-dry weight basis). NFS, native forest soil; PO, pre-mined overburden.

sieve. Soil texture was determined by hydrometer method<sup>3</sup>. Water-holding capacity and organic carbon (by Walkley and Black's rapid titration method) were determined according to Piper<sup>4</sup>. The pH was determined electrometrically in soil–water suspension (1:2.5 ratio), the total nitrogen content by micro-Kjeldahl digestion–distillation method, using a Tecator's Kjeltac auto 1030 analyser. Extractable phosphorus was determined by phosphomolybdo blue colour method<sup>5</sup>. Exchangeable cations (K, Ca, Mg, Mn, Zn and Fe) were extracted with ammonium acetate extractant (pH 7) and determined by a Perkin-Elmer 2380 atomic absorption spectrophotometer<sup>6</sup>. Available sulphur was extracted with Morgan's solution and determined turbidimetrically following Chesnin and Yien<sup>7</sup>.

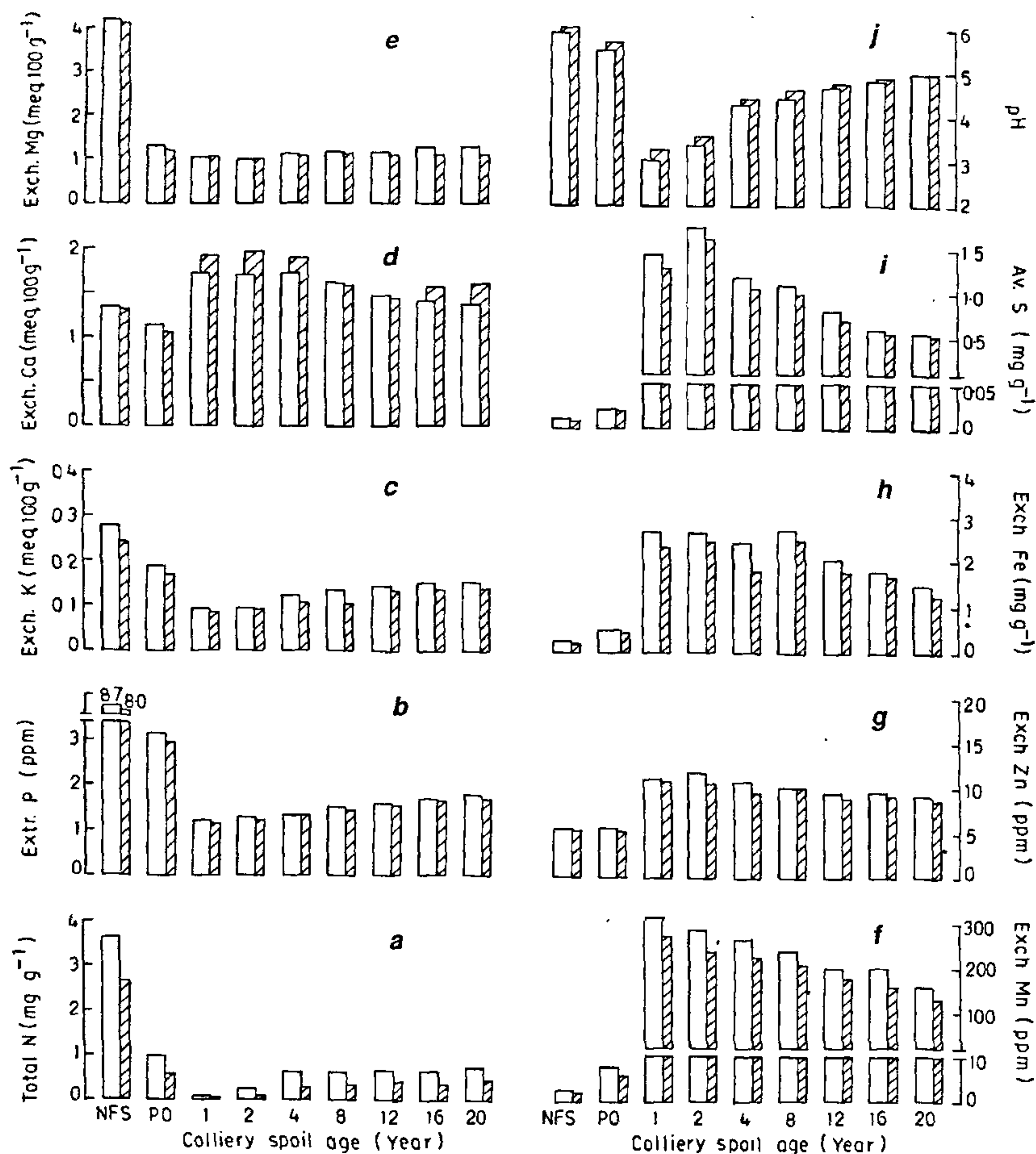


Figure 7. Elemental concentrations in colliery spoils across development sequence. NFS, native forest soil; PO, pre-mined overburden. Blank bars for topsoil and hatched bar for subsoil. The maximum coefficient of variation was 21% for exchangeable manganese for two-year spoil.

## Results

### Land degradation

The soil from mined area had on the whole lower pH, C, N (exception being the AAF site) and P (Figures

4a-d), and higher Mn, Zn, Fe and S (Figures 4e-h) than the soil from control area at both the depths and in all the microsites, i.e. CHT, CHS, CAF and AAF; CHT and AAF microsites in mined area had higher C than those in control area. Among microsites, CDA showed minimum pH and P, and maximum C, Mn, Zn, Fe and



S. The pH was generally higher in subsoil than in topsoil; for all other elements the values were higher for topsoil than for subsoil.

#### *Nutrient recovery in colliery spoil with age*

The gross physical structure of pre-mined overburden (PO) soil was very similar to that of the control and native forest soil (NFS; Figure 5). The one-year spoil differed drastically from PO and NFS in that there was (a) a steep increase in gravel proportion in the total substratum and sand particles in the soil, and (b) a decrease in the clay and silt proportion. However, with increase in age of the colliery spoil, there was an increase in soil content and decline in gravel proportion in the total substrate; further there was an increase in clay and silt proportion and decrease in sand proportion in soil. The water-holding capacity (WHC) of the soil decreased significantly from PO to one-year spoil ( $P < 0.01$ ); and with age, the colliery spoils showed a gradual but continuous increase in the WHC (Figure 6).

The acid-base status of colliery spoils, reflected in pH values, revealed that the acidification in young spoil was extremely high and could inhibit the growth of virtually all plant species (Figure 7j). During 20 years of mine spoil recovery, the pH increased remarkably, from 3.02 to 4.97 in topsoil and 3.22 to 4.98 in subsoil. The recovery between second and fourth year spoils was maximum. However, the recovery in pH of the 20-year-old colliery spoil was still significantly ( $P < 0.01$ ) lower than that of NFS and PO.

N, P and K levels were minimum in one-year colliery spoil (Figure 7a-c). N recovered at a relatively higher rate during the first four years than the later sixteen-year period. P exhibited a consistently increasing trend. K remained unchanged till two years of spoil age and increased thereafter consistently. In 20 years, N recovered by 72% in topsoil and 84% in subsoil, P by 50% in topsoil and 48% in subsoil, and K by 63% in topsoil and 57% in subsoil. However, the recovered levels of N, P and K in the spoil were significantly lower than those in PO and NFS ( $P < 0.01$ ). The concentrations of Ca and Mn in one-year colliery spoil and S in two-year spoil were very high ( $P < 0.01$ ) compared to the reference PO and NFS soil (Figure 7d, f, i). On account of up-side-down change in the overburden structure during excavation of pits and dumping of debris, deeper soil horizons, which are generally rich in calcium, occupy the surface position in the spoil and thereby spoils contain high calcium. Mn levels are increased in the spoil due to mixing of coal particles, and S levels due to oxidation of pyrite. With progression in time, Ca concentration declined by about 20%, both in topsoil and subsoil, Mn by 49% in topsoil and 52% in subsoil and S by 61% in topsoil and 57% in subsoil.

Mg was significantly lower ( $P < 0.01$ ) and Zn was significantly higher ( $P < 0.01$ ) in one-year spoil than PO and NFS (Figures 7e, g). With the ageing of the spoil, both Mg and Zn did not show any significant change. Fe was also maximum in one-year spoil and did not change up to 8 years, but subsequently it declined (Figure 7h). The overall decline in 20 years was 44% in topsoil and 47% in subsoil. Nevertheless, Fe level even after 20 years of recovery was 5-6-fold greater in the spoil than PO and NFS.

#### Discussion

In the present study, both physical and chemical properties of colliery spoil exhibited recovery, though partially, to the characteristic level of the reference overburden soil over a period of 20 years. The soil development was marked by depletion in gravelly nature of the total substratum and an increase in clay and silt fractions in spoil with age. The pH, N, P and K which declined consequent to mining increased with spoil age. Conversely, Ca, Mn, Fe and S, which increased consequent to mining, decreased with spoil age. The Mg and Zn concentrations did not change with time. Studies elsewhere have recorded the development of soil A-horizon with the age of mine spoil<sup>8</sup>, an increase in the number of actinomycetes, bacteria<sup>9</sup> and fungi<sup>10</sup>, an increase in microbial respiratory activity<sup>11</sup>, ATP levels<sup>12</sup>, soil microbial C, N and P (ref. 13) and the density and stability of plant communities<sup>14</sup>.

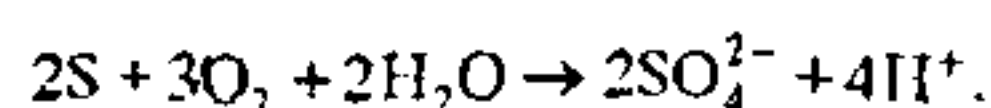
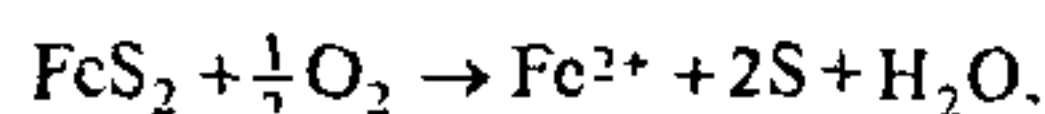
Bradshaw<sup>15</sup> argues that the starting material for succession is skeletal in systems like mine spoil, which have evolved by a violent form of ecosystem disturbance and consequently lack both in vegetation and a consolidated soil structure. Therefore, the succession on these systems is primary (a slow process) rather than secondary (a rapid process). Several factors and their interactions control the nutrient regeneration during succession (ecosystem redevelopment) in the colliery spoils. Most important among these factors are: (a) the edaphic conditions of the site itself, especially, the substratum which has to undergo weathering; (b) addition of organic matter from the vegetation; (c) microbial populations; (d) climatic factors, particularly rainfall, and (e) biotic interference (fertilization of the site, grazing and trampling which cause soil compaction and urinary additions). Unlike other elements, the build-up of nitrogen in soil depends primarily on precipitation and biological fixation, and not on the weathering process because nitrogen is not a constituent of soil minerals.

Mellinger and McNaughton<sup>16</sup> and Pandey and Singh<sup>17</sup> found that the rate of change in the soil nutrient declines as the succession progresses, and a stage is



reached when the nutrient enrichment of the soil becomes stable. We observed neither any such consistent pattern of change in the rate of spoil nutrient enrichment nor a stage towards stable nutrient status was reached. Since the present study is limited to only 20 years of succession, we suppose that this much time is inadequate to see a situation when the nutrient stability in the spoil is attained.

The principal chemical factor limiting plant growth in colliery spoil is often the extreme acidity caused by oxidation of iron pyrites ( $\text{FeS}_2$ ) in the following manner<sup>18</sup>:



Initially, the pyrite reacts with the oxygen dissolved in the soil water to form  $\text{Fe}^{2+}$  and elemental sulphur. The sulphur formed is oxidized in the second step to sulphate. The amount of acid released in the reaction corresponds to 4 moles of  $\text{H}^+$  per mole of pyrite. At pH values near the neutral point, the oxidation of pyrite is a relatively slow process which is accelerated only as acid concentration increases<sup>19</sup>. During active breakdown of pyrite, the surface water of the soils frequently assumes an intensive rust-brown colouration due to the presence of colloidal  $\text{Fe}^{3+}$  ions<sup>20</sup>.

The acidification of the soils inhibits the activity of the microorganisms and thus the mineralization of the nutrients derived from the breakdown of organic matter. Also associated with the increase in the concentration of acid ( $\text{H}^+$ ) is the increase in solubility of phytotoxic elements ( $\text{Al}^{3+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$ ), and when the pH continues to fall below 3.5, the  $\text{H}^+$  ion concentration itself affects the plant growth<sup>19</sup>. High iron and aluminium concentrations limit the availability of phosphate by fixing plant-available phosphate into hard-to-dissolve iron and aluminium phosphates at low pH levels. On the return of reducing conditions, however, iron phosphates become once again available to the plants.

The present study shows that besides the land directly hit by mining (mine spoil), other areas under different land use are also affected by coal dust through agencies like wind and water. This emphasizes the need to consider the deleterious effects of the widespread mining practice and to have patent plans to reconstruct the ecosystems on different microsites.

## Conclusion

One of the major problems which would have a serious impact on the establishment of plant cover and nutrient regeneration in colliery spoils is extreme acidity. Associated with it are the levels of Mn, Zn, Fe and S which approach toxic limits. These problems arise

simply because of up-side-down change in substratum structure of the spoils consequent to mining. The problem could be tackled in two ways: (a) by chemical treatment of such potentially toxic ion-producing material, and (b) by backfilling of the pits from where the overburden has been removed. The former technique requires large amounts of limestone to add to the spoils so that they could be neutralized. Researches have indicated that even this does not offer a permanent solution as the spoils start becoming acidic again by cumulative accumulation of hydrogen, sulphur and iron ions that are being continuously produced by oxidation of pyrite<sup>21</sup>. Therefore, further additions of limestone at certain intervals would be required, rendering the restoration efforts very expensive. The backfilling technique would involve segregation of the soil horizons and their replacement in the same order as removed during mining. The advantages of this technique are many, e.g. problems like acidification and re-acidification of the site are minimized as the pyrite component is buried deep down, the soil structure is maintained, and the technique is cost-effective. Initiatives by the government in the shape of a law are required in this direction so that the approximate original contour of the site could be maintained and the affected land could be reclaimed at a relatively much faster rate.

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# K/Ar cooling ages from Zaskar Himalaya: implications for the tectonics and exhumation of Higher Himalayan metamorphic complex

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**New K/Ar ages determined on biotite, muscovite and hornblende separates from the Higher Himalayan Crystalline (HHC) rocks in the Zaskar region, NW India, are presented. The implications of these Cenozoic ages on the timing of regional metamorphism, exhumation history of the HHC and extensional tectonics within the Higher Himalaya are discussed.**

OF all the domains of the Himalaya (Figure 1), the Higher Himalayan Crystalline (HHC) belt with many snow-capped peaks of >6000 m height represents the greatest uplift and denudation history. The HHC rocks are separated from the Lesser Himalaya to the south by the Main Central Thrust (MCT) system<sup>1,2</sup> and from the overlying Tethyan sedimentary rocks by a normal fault of regional dimension, called the Zaskar Shear Zone (ZSZ)<sup>3</sup>, Trans-Himadri Fault<sup>4</sup>, North Himalayan Normal Fault<sup>5</sup> and South Tibetan Detachment System<sup>6</sup>. The HHC rocks form the main metamorphic belt of the Himalaya, exhibiting Barrovian regional metamorphism with polyphase deformation related to the India-Asia collisional tectonics<sup>7-11</sup>. These rocks were once deep-seated, but now occupy high summits. Geologists' interest in the HHC (variously called the

Central Crystalline in Kumaun and the Tibetan Slab in Nepal) dates back to the 19th century, but in the recent decade, there has been a focus on quantitative analyses of the HHC towards a better understanding of the tectonic and petrologic processes that have shaped the Himalaya. Isotopic ages providing the time-temperature pathways of rocks constitute an important component of such a database.

Here we report new K/Ar ages determined on biotite, muscovite and hornblende separates from metamorphic and granitic rocks in the Zaskar region of the Higher Himalaya, northwest India (Figures 1 and 2), and discuss the geologic implications of our age data.

## Tectonic setting of Zaskar Himalaya

Zaskar Himalaya offers well-exposed sections of the HHC and the Tethyan sedimentary sequence (Figure 2). The geological setting, metamorphic history and plate-tectonic evolution of the region have been presented by several researchers<sup>11-29</sup>.

The HHC belt is about 10-15 km thick, with Proterozoic to Early Palaeozoic crystalline complex of gneisses, schists, amphibolites, deformed two-mica granites and migmatites. Rb/Sr isochrons determined for the Himalayan crystalline rocks in NW India have revealed three major plutonic events of 1800-2000, 1100 and 500 Ma (refs. 30, 31) like the northern parts

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