Pottery and Agriculture (ed. Yasuda, Y.), International Research Centre for Japanese Studies, YRCP, 2002, pp. 273–296.
40. Saraswat, K. S., Plant economy of early farming communities. In *Early Farming Communities of the Kaimur (Excavations at Senwar, 1986–87, 1989–90)* Vol. II (ed. Singh, B. P.), Publication Scheme, Jaipur, 2004, pp. 416–535.
41. Savithri, R., Studies in archaeobotany together with its bearing upon socio-economy and environment of Indian proto-historic cultures. Ph D thesis, BSIP, Lucknow, 1996.
42. Sharma, A., Further contribution to the palaeobotanical history of crops. Ph D thesis, BSIP, Lucknow, 1983.
43. Saraswat, K. S. and Pokharia, A. K., Plant economy at Lahuradewa: A preliminary contemplation. National Seminar on the Ganga Plain, Abstr., Directorate of Archaeology, Govt UP, December 2004, pp. 46–47.

ACKNOWLEDGEMENTS. We thank Dr N. C. Mehrotra, Director, Birbal Sahni Institute of Palaeobotany, Lucknow and Prof. M. P. Singh, Head, Department of Geology, Lucknow University for providing working facilities. We appreciate the discussion with Dr R. Tewari, Lucknow regarding archaeological aspects of this study. We also thank Dr K. S. Saraswat for discussion and permission to use unpublished information on cultivated rice. We also extend our gratitude to the anonymous reviewers whose comments helped in improving the manuscript. Financial assistance (JRF) to A.S. from CSIR, New Delhi is highly acknowledged.

Received 7 June 2005; revised accepted 2 February 2006

Lichenometry of yellow *Rhizocarpon geographicum* as database for the recent geological activities in Himachal Pradesh

Ravinder Kumar Chaujar

Wadia Institute of Himalayan Geology, Dehra Dun 248 001, India

In the present study, the growth rate and colonization delay of yellow *Rhizocarpon geographicum* species of lichen are recorded to date recent geological activities at four different localities in Himachal Pradesh. The study involved the measurement of the largest sized specimen growing on the well-dated monuments. Correlation of size with age, by plotting the measurements on a graph and finding the best fit line, gives the rate of growth of lichens (per year) and colonization delay, the time taken by the lichen to grow on a surface after its exposure to the atmosphere. It has been found that colonization delay and growth rate in the four localities namely Sanjoli, Kanlog (both in Shimla), Dharamshala and Dalhousie are 24, 68, 50, 86 yrs and 0.73, 0.79, 0.56, and 0.54 mm/yr respectively. Colonization period was also confirmed by the absence of lichens on the recent monuments prior to the calculated dates. The database will be useful to date the recent geological activities in the region.

Keywords: Colonization delay, growth rate, lichenometry, monuments, *Rhizocarpon*.

LICHENS are made up of algae and fungi, where the algae perform photosynthesis and supply the community with nutrients, and fungi take up water and minerals and shelter the algae in a greenhouse. In the present study an attempt has been made to find the growth rate and colonization delay of lichens in the Himalaya. Colonization delay is the time taken by the lichen to grow on a surface after its exposure to the atmosphere. Four different localities in Himachal Pradesh (HP) namely Sanjoli and Kanlog (in Shimla), Dharamshala and Dalhousie were selected to date various geological activities in the region. Shimla is situated at lat. 31°4′30″ and long. 77°10″, at a height 2205 masl. Lichens with known dates found in the Kanlog area (south of Shimla, at a height of 1980 m, is studded with dense deodar forest) and Sanjoli area (north of Shimla, at a height of 2360 m, studded with open deodar forest in the surrounding area). Dalhousie is situated at a height of 2039 m in the outer slopes of Dhauladhar range at long. 75°47′51″ and lat. 32°32′24″. Dharamshala is situated around lat. 32°12′ and long. 76°18′35″.

Growth rate and colonization delay will help in finding the dates of lichens on a rock surface that is exposed to the atmosphere in the surrounding regions. This will directly give the age of the activity that has exposed that surface/boulder. Further, the database will help in dating the old landslides by measuring the biggest lichen on the exposed surface of boulders; finding history of landslides – reported or unreported[1] in a particular area; dating structures generated by prehistoric earthquakes[2,3] and assessing the influence of climate[4] and local microenvironment on lichen growth rate.

The study is based on lichen size/age correlation and lichen population distribution using approaches described by Winchester and Harrison[5,6]. Lichenometry is a technique used to find relative or absolute date of rock-surface exposure. Details of the technique and criticisms have been published earlier[7–9]. The dating range depends on specific species and environmental factors; in temperate environments some foliose forms might survive about 150 years, minute crustose forms can provide dating over 400 to 600 years; and at high latitudes, dating may exceed 1000 years[10]. Absolute dating is based on the size of the largest surviving lichen. Therefore, reference to their specific details should be taken as minimum approximations only. Other factors leading to lichen mortality and renewed colonization are: competition for growing space on the rock surface, vegetation growth, animal or human interference, weathering or other geomorphologic processes.

The most common lichen growing on the slope boulders is *Rhizocarpon geographicum* (Figure 1 *a*). It belongs to

e-mail: r_chaujar@hotmail.com

Table 1. Size (largest)/age (in mm/date) of various types of lichens in the four localities on different monuments

Lichen variety	Kanlog	Sanjoli	Dharamshala	Dalhousie
Dark grey	180/1878	80/1949	60/1876	95/1873
Light grey			130/1863	140/1869
Greenish	82/1872		95/1863	100/1880
Brown			45/1874	
Yellowish brown			50/1885	

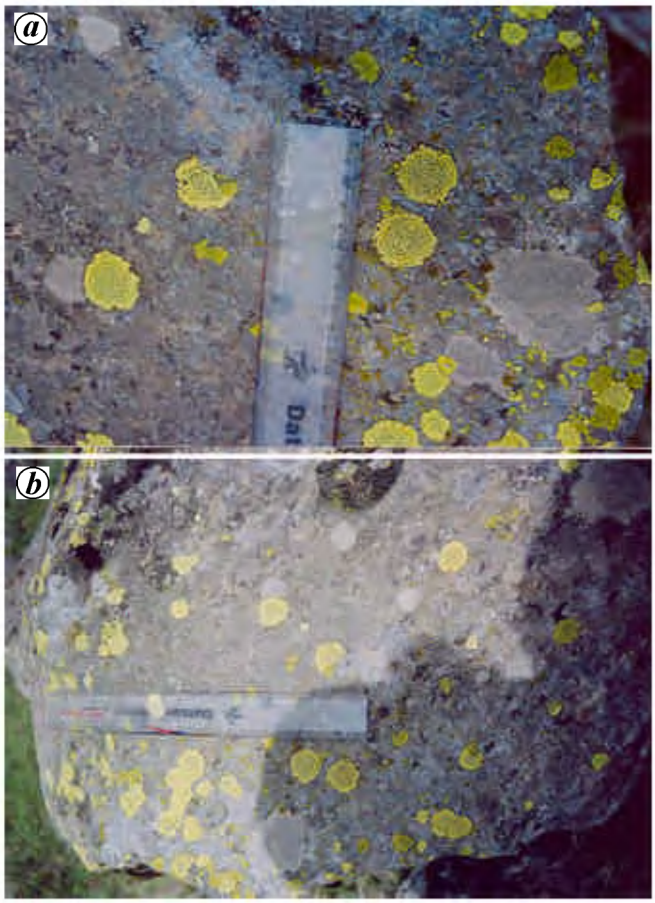

Figure 1. *a*, Types of *Rhizocarpon geographicum* lichen present in the area. *b*, Yellow *Rhizocarpon* and other species of lichens in the region.

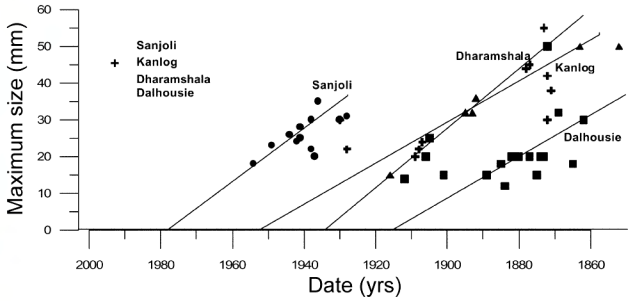

Figure 2. Growth curve constructed from largest yellow *Rhizocarpon* (geographic species) thalli measured in different parts of Himachal Pradesh, to find their growth rate and colonization delay.

Table 2. Colonization delay and growth rate of lichens in different parts of Himachal Pradesh

Location	Colonization delay (yrs)	Growth rate (mm/yr)
Sanjoli, Shimla	24	0.73
Kanlog, Shimla	68	0.79
Dharamshala	50	0.56
Dalhousie	86	0.54

the yellow-green *Rhizocarpon* section most frequently used in lichenometry. Longest axes of all the lichens of this species growing on the upper faces of selected boulders were measured with a flexible tape, to the nearest mm. Growth curves were constructed to find the growth rate for the species, with measurements of maximum diameter of the largest specimens growing on different monuments of known dates in the three cities of HP. A large variety of lichens (Figure 1 *b*) is present in the area, among which dark grey, light grey, green, brown and yellowish brown varieties occur frequently. They cannot be used for dating purposes, as their growth is not uniform. The size and age of the largest lichens of these varieties in different parts of the area are shown in Table 1.

A total of about 250 lichen thalli were measured at four different localities in HP. Among the large number of lichen species found in the area, only the largest lichen of the reliable species *Rhizocarpon geographicum* growing on the various monuments made up of granite, sandstone, impure marble (siliceous) and quartzite were measured. The size, position, height above ground and aspect of each measured specimens were noted along with the dates. These size measurements were graphically plotted against the age of the monuments, and line of best fit was drawn (Figure 2). In a few cases, it has been found that the largest lichens on the monuments may or may not be founder members of their population. Similarly, slightly smaller thalli could either be later colonizers in the same population or a founder member of a younger population.

A growth rate (mm/yr) was established and a colonization period was set using the lines of best fit on data of

lichens on monuments of known dates (Table 2). Colonization period was also confirmed by the absence of lichens on the new monuments prior to the calculated period.

The above results were also verified by calculating the dates using growth rates of yellow *Rhizocarpon* specimen (32 mm in diameter) occurring on the side rock before tunnel no. 100 on Kalka–Shimla railway track and a 30 mm diameter lichen on a rock near the Summer Hill Station (close to Shimla). On calculation we get 30 mm/0.79 = 37.9, say 38 years + 68 (colonization delay) = 106 years + 2 years (as the data were collected in April 2003) = 108 years.

This rail project was started in the year 1897, construction was done during 1901–03, and the first train started in November 1903 (data collected from Station Master, Shimla). The rock-cutting must have started between 1897 and 1901. If we take 1898 as the date of rock-cutting, then the age turns out to be 107 years, which is quite close to that calculated using lichen size.

In the Sanjoli cemetery, lichen 32 mm (diameter) on the gravestone of Harry James Barters, who passed away in November 1936 (age of monument 69 years; another 6 to 8 months for stone erection after burial) gives an age of 32/0.73 (growth rate) = 44 + 24 (colonization delay) = 68 + 2 = 70 years, which is almost the same as the actual age.

In St. John Church, Dharamshala, on the main memorial stone of James Bruce behind the church dated 1863 (age of memorial 142 years), a yellow lichen (50 mm of diameter) gives the age of 50/0.56 = 88 + 50 (colonization delay) = 138 + 2 = 140 years, which can be compared with the age of the memorial.

In the Dalhousie graveyard below the bus stand, a 20 mm yellow lichen was found on a 1880 monument (125 yrs), which gives an age of 20/0.54 = 37 + 68 (colonization delay) = 123 + 2 = 125 years.

The above results (Table 2) show that a new calibration of growth rate of lichens and colonization delay is required in the regions that have experienced environmental changes, irrespective of distance, as shown by the data from Sanjoli and Kanlog which are hardly 3 km apart aerially. The result of the present study shows that the statement by Tucson[11] 'What makes lichenometry work is that lichens grow at a specific rate in any region of about 10,000 sq. miles', is not true.

Similarly, the opinion of Denton and Karlen[12], and Bull *et al.*[13] that 'a new calibration of lichen is not necessary at every site in the study region because factors such as substrate lithology and smoothness, mean annual precipitation and temperature, and length of growing season appear to have a minimum effect on colonization times or lichen growth rate. However, shelter from sun and wind promotes faster lichen growth[14]. The same is true in case of Kanlog lying in the dense deodar forest, where shelter from the sun and wind is more compared to Sanjoli which is in the region of less vegetation and is surrounded by open deodar forest.

1. Winchester, V. and Chaujar, R. K., Lichenometric dating of slope movements, Nant Ffrancon, North Wales. *Geomorphology*, 2002, **47**, 61–74.
2. Bull, W. B., Dating San Andras fault earthquake with lichenometry, *Geology*, 1996, **24**, 111–114.
3. Bull, W. D. and Brandon, M. T., Lichen dating of earthquake generated regional rockfall events, Southern Alps, New Zealand, *Geol. Soc. Am. Bull.*, 1998, **110**, 60–84.
4. Harrison, S. and Winchester, V., Nineteenth and Twentieth Century glacier fluctuations and implications in the Arco and Colonia valleys, Hielo Patagonico Norte. *Arct., Antarct. Alp. Res.*, 2000, **32**, 55–63.
5. Winchester, V. and Harrison, S., A development of the lichenometric method applied to dating of glaciological influenced debris flows in Southern Chile. *Earth Surf. Process Landforms*, 1994, **19**, 137–151.
6. Winchester, V. and Harrison, S., Dendrochronology and lichenometry: an investigation into colonization, growth rates and dating on the east side of the North Patagonian Ice field, Chile. *Geomorphology*, 2000, **34**, 181–194.
7. Webber, P. J. and Andrews, J. T., Lichenometry, a commentary. *Arct. Alp. Res.*, 1973, 5, 295-3-2.
8. Locke, W. W., Andrews, J. T. and Webber, P .J., *A Manual for Lichenometry*, British Geomorphological Research Group, Technical Bulletin, vol 26, 1979, pp. 1–47.
9. Innes, J., Lichenometry. *Prog. Phys. Geogr.*, 1985, **9**, 187–254.
10. Winchester, V. Lichenometry. In *Encyclopedia of Geomorphology* (ed. Goudie, A. S.), Routledge, 2004, pp. 619–620.
11. Tucson, A., Algae, fungus dates prehistoric earthquakes. *The News March 10- Times Regional News*, 1998.
12. Denton, G. H. and Karlen, W., Lichenometry, its application to Holocene moraine study in Southern Alaska and Swedish Lappland. *Arct. Alp. Res.*, 1973, **5**, 347–372.
13. Bull, W. B., King, J., Kong, F., Moutoux, T. M. and Philips, W. M., Lichen dating of coseismic landslide hazards in alpine mountains. *Geomorphology*, 1994, **10**, 253–264.
14. Benedict, J. B., Recent glacial history of an alpine area in Colorado Front Range, USA. 1. Establishing a lichen growth curve. *J. Glaciol.*, 1967, **6**, 817–832.

ACKNOWLEDGEMENTS. I thank the Director, Wadia Institute of Himalayan Geology, Dehradun for providing necessary facilities to carry out the present study. Discussions with Dr V. Winchester, School of Geography, Oxford University, UK are also acknowledged. I also thank my colleague Dr P. S. Negi for help during field work.

Received 27 July 2005; revised accepted 30 January 2006