A NATURAL HERITAGE APPROACH TO THE REHABILITATION OF SOUTHERN ONTARIO'S LIMESTONE QUARRIES

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Abstract

Southern Ontario's disused pits and quarries are typically viewed as visually unattractive landscape features that must be transformed into agricultural lands or turf-style recreational areas. This type of rehabilitation involves the costly and labour intensive processes of backfilling, site grading, landscaping and maintenance. These processes introduce artificial elements into the landscape, contributing to its' already fragmented and unnatural character.

This paper presents a cost-effective rehabilitation approach consistent with Provincial and Regional natural heritage objectives. The natural heritage approach involves changes in how we view abandoned quarries and how we manage their rehabilitation. Although this concept can be applied to abandoned pits, the focus of this paper will be on limestone quarries. The first step is to view abandoned quarries as potentially beautiful landscapes that could be habitats for rare and common native species of vegetation and wildlife. The second step is to look at the natural analogs of limestone quarries that occur in southern Ontario, namely the Niagara Escarpment and alvar habitats, for models of natural rehabilitation.

Research conducted by the principal author in southern Ontario and others in Great Britain has shown that, given time and the proper environmental conditions, abandoned quarries will develop vegetation communities comparable to those found in their natural analogs. Several modifications of existing quarrying practices, such as the use of restoration blasting, in conjunction with seeding and planting of site-appropriate native species have been shown to accelerate the processes of natural revegetation. A natural heritage approach to rehabilitation should work towards embracing natural successional processes so that disused pits and quarries are transformed to natural endpoints within the landscape.

Introduction

Current policy in Ontario requires site rehabilitation plans in support of applications for new or expanded quarry extraction. Although rehabilitation can entail attempts to restore the quarry to a former land use, this is not always required and is often neither practical nor desirable. Depending on the location and size of a quarry, as well as the objectives of the key stakeholders, a former quarry may be rehabilitated to agricultural, silvicultural, residential, commercial, industrial, recreational or "natural" (i.e. conservation) lands (Mackintosh and Hoffman 1985; Hilditch et al. 1988; Yundt and Augaitis 1992).

There has been a significant amount of research on and discussion of quarry rehabilitation for agricultural, silvicultural and recreational purposes, but restoration tfor conservation has been only explored to a limited extent in Ontario. Key recommendations have typically involved backfilling, costly importation of sub-soil and topsoil, and plantings of trees and shrubs that are not native and/or not suited to the rigours of a quarry habitat (Lowe 1979; Hilditch et al. 1988; Yundt and Augaitis 1992). The natural heritage option presents the greatest ecological potential, but is seldom selected due to lack of available research.

Although limestone quarries in Ontario are typically considered unsightly and potentially dangerous landscape features, there is a growing recognition among rehabilitation scientists and practitioners that these sites represent opportunities for the creation of relatively high quality, self-sustaining ecological landscapes. Current research in Ontario and Great Britain has shown that given time and the right environmental conditions, disused quarries become colonized with flora and fauna comparable to that of natural analogs in those regions (Coppin and Bradshaw 1982; Gunn et al. 1992; Wheater and Cullen 1997; Ursic et al. 1997). These anthropogenically created landscapes provide potential refuges for rare and uncommon native species, as well as potentially valuable passive recreation facilities, if safety issues are addressed.

The focus of this paper will be the natural heritage approach to limestone quarry rehabilitation, based on the authors' familiarity with the geology and vegetation dynamics of limestone habitats. However, this approach canalso be applied to gravel pits which have simliar natural analogs (beaches, barrens and bluffs) in Ontario.

Historical Context

Limestone has been quarried in southern Ontario for more than 250 years, with the first pits operating in the vicinity of present-day Toronto in the 1720's (Yundt and Augaitis 1992). Until the 1900's, most of these quarries were excavated manually using 'plug and feather' techniques which removed individual blocks of stone along existing bedding planes of naturally exposed escarpments. These relatively small, exposed limestone faces, if left intact, were typically surrounded by existing natural vegetation communities and became re-colonized, blending in with the natural landscape within several decades. The introduction of primitive blasting methods, using black powder, resulted in stable, heterogeneous quarry faces containing microsites for colonization by local vegetation.

The advent of modern explosives and the increasing demand for limestone for use in roads and urban structures, caused quarries to changed dramatically in size and appearance. Modern explosives (TNT, ANFO) expand rapidly at high temperature and pressure, causing an intense shock wave which results in a highly fractured, uniform sterile face (Gunn et al.1992; Gunn and Bailey 1993). Modern transportation and limestone processing technologies have permitted more intensive extraction, resulting in larger and deeper quarries that frequently extend below the water table. Large quarries, with unstable walls and frequent isolation from analogous natural vegetation communities, take much longer to become colonized, and therefore require considerable planning and active management if they are to blend into the existing natural landscape within a reasonable time frame.

All current quarry operators in Ontario must submit a detailed rehabilitation plan prior to creating a new or expanding an old quarry. Until recently, rehabilitation policies in Ontario recommended backfilling of exposed quarry walls to achieve uniform 3:1 slopes. This method is practical in situations where quarry walls are very unstable and where overburden for backfilling is readily available, but is impractical and costly where this is not the case. Under recent changes in government policy (B. Messershmidt, OMNR, pers. comm. 1998) backfilling to a 3:1 slope is no longer required if this can be justified in the context of the rehabilitation strategy for a given site.

Despite this policy shift, many operators continue to rehabilitate their lands to agricultural, commercial or conventional recreational (i.e. turf landscapes) uses as indicated in their original site plan, utilizing costly and labour intensive processes of backfilling, site grading and landscaping. These approaches continue to be selected in part because key personnel are not familiar with other alternatives.

The concept of approaching pit and quarry rehabilitation from a natural heritage perspective is not new, and has been under study for two decades in Great Britain. Beginning in 1978, J.G. Kelcey presented arguments that derelict land is a valuable resource and provided tremendous opportunities for wild recreation areas. In the context of otherwise homogenous agricultural landscape of Britain, the ecological value of disused limestone and chalk quarry habitat for nesting birds and mammals, and as refuges for rare and relict plant species, has been reported for many decades (Hepburn 1942,1955; Piggot and Walters 1954; Usher 1979). By the 1980's the recognition of disused pits as valuable natural landscape features became an incentive for conservation groups in Great Britain to purchase quarries and for government and industry to modify existing rehabilitation policies (Gunn et al. 1992).

Developing a Natural Heritage Approach

Current provincial planning policies in Ontario advocate a natural heritage approach for regional and municipal planning (OMNR 1997). Central tenets of this approach include the preservation of existing landscape physiography and core natural areas, reconnection of habitat fragments, and restoration of impacted lands to communities that occur naturally in the region. Insofar as quarry rehabilitation is concerned, we broadly define the natural heritage approach as the creation of self-sustaining, natural terrestrial and aquatic ecosystems that are compatible with existing site conditions and habitat types of the ecoregion. An example of natural heritage rehabilitation would include the creation of cliff and talus (rockfalls at the base of cliffs) habitats in quarries located adjacent to the Niagara Escarpment, or the creation of alvar or wetland habitats on quarry floors. The key elements of this approach involve a) developing an understanding of key physical attributes and processes of a site, b) recognizing ecologically appropriate natural habitat models or analogs for use in rehabilitation, and c) incorporating habitat components and suitable native species in re-vegetation and habitat reconstruction.

These approaches for limestone quarry rehabilitaion have been explored in Ontario and Great Britain. In Britain, the government-supported Limestone Research Group (LRG) has developed practical and cost-effective techniques for progressive rehabilitation of quarry margins since the mid-1980's. Using the structure and vegetation communities of natural limestone dalesides (similar to the cliffs of Ontario's Niagara Escarpment) as landscape models, they have developed a number of techniques and strategies that promote the replication of daleside landforms, including "restoration blasting" (Gunn et al. 1992), as outlined in the "Restoration Strategies" section of this paper.

In southern Ontario, there has been some research by the Ontario Ministry of Natural Resources (OMNR), Aggregate Producers Association of Ontario (APAO) and researchers at the Cliff Ecology Research Group (CERG) at the University of Guelph. This research, although less applied than the work conducted by LRG, has shown that limestone quarries in southern Ontario will develop natural plant communities comparable to those found on the Niagara Escarpment (Ursic et al. 1997), given adequate time and appropriate site conditions. The Niagara Escarpment, a UN Biosphere Reserve that extends from Manitoulin Island to Niagara Falls in Ontario, contains cliff faces and talus slopes that provide an excellent natural analog for quarry rehabilitation. Depending on site hydrology, alvar (limestone pavements), mineral fens (calcareous wetlands) or shallow bedrock savannas could also be appropriate natural analogs for quarry floors.

Ursic *et al.* (1997) recorded 255 species of vascular plants, bryophytes (mosses) and lichens in their study of abandoned limestone quarries, indicating that these sites provide habitat for diverse species belonging to various life forms. However, what is more interesting is that the proportion of native to exotic vascular plant species was 60:40, a good ratio considering these sites are primarily colonized by ruderals (early successional species). Furthermore, much of the native vascular plant and bryophyte component also occurs naturally on Niagara Escarpment cliff faces, talus and tops (Table 1; Cox and Larson 1993; Larson et al. 1989). Examples of less common native Escarpment cliff vascular plant species recorded in abandoned quarries but not listed in Table 1 include *Asplenium trichomanes, Pellaea glabella, Cystopteris fragilis, Acer rubrum, Ulmus americana, and Aster ericoides.*

Table 1. The most frequent species/genera observed in a study of abandoned quarry faces, floors and tops in southern Ontario (from Ursic 1994). Percent relative abundance (% R.A.) shown. Species/genera also known to occur commonly on Niagara Escarpment cliff face (ú), cliff top and edge (+) and talus (*) (Cox and Larson 1993; Larson et al. 1989) are indicated.

Quarry Face Species	% R.A.	Quarry Floor Species	% R.A.	Quarry Top Species	% R.A.
Poa compressa. ú*	10.45	*Poa compressa.* ú*	12.28	*Poa compressa.* ú*	10.59
Hieracium spp.	4.99	*Hieracium* spp.	4.17	*Hieracium* spp.	6.51
Erigeron philadelphicus.	4.84	*Daucus carota*	4.17	*Daucus carota*	4.54
Verrucaria nigrescentoidea	4.57	*Solidago spp.**	3.98	*Solidago spp.**	4.38
Chrysanthemum leucanthemum	3.86	*Erigeron* spp.	3.62	*Trifolium campestre*	3.62
Thuja occidentalis+*	3.72	*Phragmites australis*	3.15	*Coronilla varia*	2.99
Solidago spp.*	3.52	*Thuja occidentalis*+*	2.67	*Plantago lanceolata*	2.39
*Taraxacum officinale**	3.26	*Agropyron repens*	2.29	*Bromus inermis*	2.28
Daucus carota	3.14	*Silene vulgaris*	2.20	*Agrostis gigantea**	2.11
Lepraria lobificans	2.87	*Cystopteris bulbifera**	2.04	*Phleum pratense*	2.09

Alvars or limestone pavements are naturally flat, open areas with little or no soil that contain some of the most diverse and rare vegetation in North America (Catling and Brownell 1995). These habitats are considered globally rare, but and are still largely unknown to the general public. Alvars provide ideal models for quarry floor rehabilitation since they require little or no soil and are capable of supporting species adapted to extremes in temperature and moisture. Unfortunately, there is very little available research on re-vegetation dynamics in alvars, although CERG is presently monitoring natural recolonization of a disturbed alvar habitat in Bruce Peninsula National Park in Ontario (Dr.U. Matthes-Sears, pers. comm. 1998).

Key Physical and Biological Factors in Quarry Rehabilitation

Recognition of the physical and biological parameters that influence vegetation succession is key to understanding the development of natural vegetation communities. Cliff and alvar habitats support many rare plant and wildlife species, in addition to predictable communities of shrubs, herbs, ferns, mosses and lichens (Davis 1951; Maser et al.

1979; Larson et al. 1989; Catling and Brownell 1995). Given that many older disused limestone quarries in Ontario support similar species, natural heritage rehabilitation efforts require consideration of factors that can affect recruitment and establishment of individual species and vegetation communities.

Plant Colonization

Quarrying exposes substrates previously not colonized by plants. Similar to surfaces exposed by large-scale natural disturbances such as deglaciation, these features give rise to primary successional processes. The resulting landscape is impoverished, lacking soils and nutrients, and is exposed to extreme temperature and moisture conditions. These conditions exclude or inhibit colonization by most species common to the surrounding landscape. Species adapted to these conditions typically include weedy ruderals and less common or rare native species which require habitats free of competition.

Short-term studies in disused quarries indicate that there is initially colonization by a fairly diverse plant community dominated by ruderals and limited colonization by longer-lived and/or unusual native species (Donelan and Thompson 1980; Jefferson and Usher 1987; Skaller 1977; Usher 1979; Bradshaw et al. 1982; Davis et al.1985). However, over a longer time frame many weedy ruderals (i.e. ox-eye daisy, *Chrysanthemum leucanthemum* and wild carrot, *Daucus carota*) are displaced by more desirable native species. Ursic et al. (1997) examined re-vegetation dynamics on the vertical cliff faces of 18 abandoned limestone quarries ranging from 17 to 92 years old. They found that vegetation species richness remains high and dominated by weedy ruderals for the first 55 to 70 years following abandonment, but as neighbouring trees (primarily eastern white cedar, *Thuja occidentalis*) seed into the quarry floor and begin to shade the walls, vegetation communities become less diverse and dominated by native, longer-lived species occurring naturally on cliffs of the Niagara Escarpment. Notably, higher diversity is not necessarily a good indicator of successful rehabilitation on these sites, and monitoring of species composition is critical in evaluating site progress.

Site Age and Size

Ursic et al. (1997) determined that time since quarry abandonment was the single most important environmental variable responsible for shaping species assemblages on abandoned quarry faces. However, this factor was inextricably related to other environmental variables such as quarry size, substrate stability and the development of a dense tree canopy on the quarry floor. This is not surprising, since older quarries have not only had longer to regenerate but were generally smaller and affected by less intensive blasting techniques than more recently mined sites. It is likely that site age and size have not emerged as significant in other studies because none of them examined abandoned quarries along a chronosequence extending for almost a century.

Aspect and Latitude

The aspect of quarry walls can influence plant species diversity and composition significantly since it regulates the amount of light a particular cliff face receives and also controls moisture availability. Risbeth (1948) observed that vegetation composition changed significantly between east and west facing limestone walls. Davis (1951) found no differences between cliffs with eastern and western exposures, but observed increased species abundance on south-facing as compared to north-facing cliffs. Ursic et al. (1997) found that south-facing cliffs consistently supported more species than north-facing walls, but that more northerly quarry sites appeared to develop forest cover on the floor and top more rapidly than sites in the south. While it is rarely possible to alter the design of the quarry to change the aspect and latitude of the exposed surfaces, it is important to consider these factors in selecting site-appropriate seed or plants.

Ledges

Ledges are a horizontal component to cliff faces where organic and mineral debris can accumulate, thus facilitating plant colonization. Since many species naturally colonize ledges it is not surprising that the presence of ledges tends to increase plant species richness. Ursic et al. (1997) found that, on average, quarry wall plots without ledges supported 12 species while plots with ledges supported 14 species. Ledge frequency has also been shown to be important in controlling which species become established on cliff faces (Davis 1951; Bunce 1968). It is possible to control the extent and size of ledges by modifying blasting methods. This has been studied in limestone quarries by LRG where they were able to create different ledge sizes and blast piles by using various combinations of shot-holes and vent-holes in charge zones (Gunn et al. 1992).

Substrate Stability

The stability of quarry edges, walls and floors is a critical factor determining how quickly re-vegetation occurs and what species are able to thrive in disused quarries, and is correlated to the type of geological formation being worked. Ursic et al. (1997) found that longer-lived woody species, mosses and lichens are excluded from unstable quarry walls. However, most common ruderal herbaceous species, including annuals and biennials, were capable of reaching maturity on even the most unstable quarry walls.

Improving substrate stability has been recognized by LRG as another key objective of their "restoration blasting" technique, for both ecological and safety reasons. They have been able to improve stability of cliff faces and rock piles at cliff bases with modern explosives by modifying detonation timing and sequence, as well as the number, pattern, depth and spacing of shot-holes (Gunn et al. 1992). More research remains to be done on methods for improving the stability of rock buttresses and headwalls.

Surrounding Vegetation

The presence of natural vegetation adjacent to quarry sites will obviously also have a significant impact on the rate and type of plant recruitment. Over the longer term, the density and height of vegetation adjacent to the quarry wall is one of the most important factors affecting the course of naturalization on a site since trees which become established on the quarry floor shade and shelter the quarry wall. The density and size of tree and shrub canopies on the quarry floor influences the quarry wall plant assemblages by limiting the amount of radiation that penetrates to the face, creating a cooler and moister environment. In southern Ontario, this favours native species typical of the Naigara Escarpment species, including *Thuja occidentalis, Lepraria lobificans, Cystopteris bulbifera, Cladonia cariosa* and *Marchantia polymorpha* (Ursic et al. 1997).

Restoration Opportunities and Strategies

Quarrying for limestone typically results in the formation of three distinct terrestrial landscape features or habitat types which can become naturally colonized by plants: quarry walls that can resemble natural escarpment cliff faces, floors that can resemble limestone pavements or alvars, and spoil banks or overburden piles that can resemble talus. Depending on the hydrological regime, wetland and aquatic systems may also occur. If the rehabilitation objective is to emulate natural habitats, then restoration strategies should attempt to facilitate or enhance natural colonization by introducing appropriate species to these habitats.

The key site factors described above provide a broad set of parameters for planning and implementing natural heritage rehabilitation in limestone quarries. Planning and design modifications must be initiated prior to quarry excavation since the quarrying method utilized will have a direct bearing on the kinds of surfaces created. For example, if the rehabilitation objective is to re-create natural cliff face vegetation communities, then blasting regimes should be modified when approaching the limits of the working face in order to create a stable substrate with numerous ledges. Although unstable faces will stabilize over time due to substrate settling, soil deposition and weathering, the rehabilitation objective is usually to accelerate establishment of vegetation cover.

In Great Britain, the LRG has developed a technique called "restoration blasting" designed to replicate natural landforms of the local limestone dalesides while also safely and effectively extracting limestone materials (Gunn et al. 1992). This technique reduces final face heights by constructing scree blast piles, covering the quarry face to varying heights by altering scree pile size and fragmentation, ensuring the stability of blast piles by retaining rock steps, creating cut-backs on the face, and producing rock buttresses and head walls of varying heights. Studies to date indicate that within 3 to 10 years, vegetation establishes itself more readily and develops a more consistent cover than in quarries blasted using conventional methods (Gunn et al. 1992; Wheater and Cullen 1997) although vegetative cover and species composition is not the same as that found on natural dalesides.

In addition to landform replication, LRG has experimented with a number of techniques for speeding up vegetation establishment by native daleside species. Recognizing that topsoil is not an economic or practical seedbed for this habitat, they have used existing site materials for cover such as chippings (crushed limestone), and unsterile sand mixed with peat. Hydroseeding in conjunction with pit planting of trees into the scree (equivalent to Ontario's Escarpment talus) has been quite effective. Use of mulch and peat during seedling establishment has also been helpful, but more important has been the selection of native species that are typical of dalesides and disused quarries and naturally adapted to the extant conditions (Gunn et al. 1992).

Modified blasting technologies could be used to replicate Escarpment cliff faces and talus. The use of benching and selective blasting followed by seeding (drilling, broadcasting, hydroseeding or slurry sprayed from the top of the quarry) can also help naturalize a quarry progressively (Coppin and Bradshaw 1982). Species selection must be based on an understanding of the natural communities that will form on the habitat being replicated.

Although no studies have been published to date on creation of alvar habitats, Jefferson and Usher (1987) found that many undesirable species were colonizing the floors of 3 disused chalk quarries. Consequently, they recommended a rotational scraping of small areas to encourage establishment of a rare native species-rich community and to prevent establishment of invasive species. Although it goes against "common sense" to remove topsoil to encourage plant establishment and growth, the species adapted to these habitats thrive with fewer nutrients and less competition from other plants.

In view of the findings of Ursic et al. (1997) regarding surrounding vegetation, another potentially effective strategy would be to try to maintain and/or establish tree cover with eastern white cedars at the top and base of the quarry face. This will encourage natural colonization by long-lived cliff-dwelling species, and exclude weedy ruderals. In locations where appropriate natural vegetation communities surround the quarry site, less introduction of planted materials will be required, but since trees grow slowly on these sites (Matthes-Sears and Larson 1995; Kelly et al. 1992) it may be advantageous to plant some seedlings as well.

Where woodlots or other natural habitats will be destroyed as a result of quarry operations, there are opportunities for salvage of existing biological material. This strategy will likely be most effective on quarry tops where this material can be used to create a screen during excavation and then blend into the rest of the site afterwards. While it may be impractical to move large trees, salvage of soil seed bank and propagules can be conducted effectively without double-handling if staging of quarry operations includes plans for direct transfer of materials from donor to receptor sites. Temporary storage of topsoil can also be effective as long as it is handled properly and not stored for too long (Tacey and Glossop 1980). Herbs and shrubs can also be moved successfully if this is done during the proper season (usually spring) and by contractors who ensure that plant root systems are kept intact with their associated soil and that the plants are adequately watered during and after transplant (Munro 1994). Consideration must also be given to ensuring that the donor and receptor sites are similar in topography, hydrology and aspect in order that the plants will be able to adapt.

Summary & Discussion

The benefits of allowing natural processes to rehabilitate the walls of abandoned limestone quarries include the recruitment of an uncommon but native component of biodiversity, a reduced initial cost, and a reduced long-term maintenance cost. However, the 70 to 100 year timeframe for natural recolonization is probably not acceptable in most cases, and so strategies to accelerate succession on quarry walls and floors are required. Key strategies include use of blasting methods that create more stable faces with ledges akin to those found on natural escarpments, various seeding techniques, direct planting, and the creation of suitable tree canopies on quarry floors and tops.

Although this paper has emphasized general approaches to and strategies for natural heritage after-uses for limestone quarries, it is important to note that each site will have a unique set of conditions to consider. Even among limestone quarries in southern Ontario there is variation in geological formations that directly influences the stability of the substrate and ledge frequency. For example, the Amabel and Guelph geological formations contain massively bedded dolostones, commonly used for building and armour stone (Derry et al. 1989), that provide solid bedding planes for the establishment of long lived species. Factors such as the aspect of the quarry faces and the presence and quantity of water on the quarry floor will also affect the types of vegetation and wildlife that can colonize and the kind of restoration strategy that will be required.

It is critical that realistic time frames be set for the natural heritage rehabilitation of sites. Even with the use of restoration blasting, seedbank salvage and co-plantings the rehabilitation process on these sites is slow by typical standards since only slow-growing species survive on these sites. However, given the time frames of most current quarry operations (50+ years in some cases), rehabilitation can begin to regenerate while operations are ongoing, so that by the time excavation is complete parts of the quarry will be in the advanced stages of rehabilitation.

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J.C. Duff Limited Sand and Gravel
Harrington and Hoyle Ltd.
Lafarge Canada Inc.
MacNaughton Hermsen Britton Clarkson Planning Limited
Planning and Engineering Initiatives
S.E. Yundt Ltd.
Skelton Brumwell & Assoc. Inc.

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