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Résumé de l'article

Les pierres de construction utilisées pourles édifices du Parlement à Ottawaproviennent de nombreuses carrièresautant au Canada, aux États-Unis que deplusieurs pays européens. Elles ont ététaillées, posées et sculptées suivant desprocédés précis, en conformité avec lesrègles de l'art de l'époque. La reconstruc-tion de l'édifice du centre qui est le sujetdu présent article, a été une affaire quis'est étirée étant donné les priorités lors dela Grande Guerre de 1914-1918. Cespierres de revêtement des édifices duParlement ont subi les avanies du climat,du feu, de tremblements de terre et de lapollution, et récemment, des efforts et desfonds considérables ont été consentispour la restauration des éléments demaçonnerie de tous les édifices afind'assurer la pérennité de ce site historiquenational. Le rôle déterminant du géo-logue, lors de l'évaluation initiale et duchoix des pierres, a été largement ignoréjusqu'à maintenant, mais la restaurationdes édifices a permis de remettre en valeurle rôle du géologue, parce qu'il fallaitd'abord comprendre les réactions com-plexes des pierres de construction avecl'environnement et les autres éléments demaçonnerie avoisinants, afin de pouvoirtrouver des pierres de remplacementconvenables.

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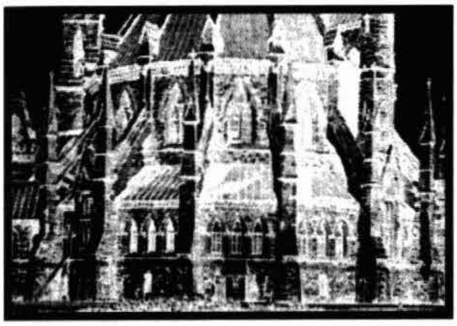

Building Stones of Canada's Federal Parliament Buildings

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SUMMARY

The building stones used in the Ottawa Parliament Buildings were mined from numerous quarries in Canada, United States, and several European nations. They were cut, placed and carved according to exacting procedures using the most up-to-date technology of the time. Construction of the rebuilt Centre Block, the focus of this article, was a protracted affair, interrupted by the demands of the 1914-1918 Great War. Exterior stone of the Parliament Buildings has endured the ravages of weather, fire, seismic shaking and pollution. Recently, great effort and expense have been devoted to the restoration of the masonry elements of all of the buildings to ensure the continued viability of this National Historic Site. The role of the geologist, critical in the initial evaluation and selection of the building stone, was largely ignored until recently. Building restoration of late has also restored the role of the geologist, with the requirement to understand the complex reactions of the building stone to the environment and its neighbouring masonry elements, and in the quest to find suitable replacement stone.

RÉSUMÉ

Les pierres de construction utilisées pour les édifices du Parlement à Ottawa proviennent de nombreuses carrières autant au Canada, aux États-Unis que de plusieurs pays européens. Elles ont été taillées, posées et sculptées suivant des procédés précis, en conformité avec les règles de l'art de l'époque. La reconstruction de l'édifice du centre qui est le sujet du présent article, a été une affaire qui s'est étirée étant donné les priorités lors de la Grande Guerre de 1914-1918. Ces pierres de revêtement des édifices du Parlement ont subi les avanies du climat, du feu, de tremblements de terre et de la pollution, et récemment, des efforts et des fonds considérables ont été consentis pour la restauration des éléments de maçonnerie de tous les édifices afin d'assurer la pérennité de ce site historique national. Le rôle déterminant du géologue, lors de l'évaluation initiale et du choix des pierres, a été largement ignoré jusqu'à maintenant, mais la restauration des édifices a permis de remettre en valeur le rôle du géologue, parce qu'il fallait d'abord comprendre les réactions complexes des pierres de construction avec l'environnement et les autres éléments de maçonnerie avoisinants, afin de pouvoir trouver des pierres de remplacement convenables.

INTRODUCTION

Canada's legislative buildings are not only the place of business for governments, they are also monuments to the social and economic progress of the jurisdictions they represent. Their design and construction has been the work of formative architects and builders. Great pains have been taken to ensure that these are significant structures, of unique design and beauty, using quality materials and built with exacting craftsmanship, worthy of the importance of the business that transpires within their walls. Canada's Parliament Buildings in Ottawa are no exception.

This is the first of a series of articles about the building stones of Canada's federal and provincial Parliament Buildings. Historians, political scientists, architects, and engineers have written at length about the buildings and their varied histories. Geologists, for the most part, have been silent. It is expected that this series will be written by a number of geologists, and may cover all provinces and territories to document the stories of the stones themselves.

The Federal Parliament Buildings are perhaps Canada's finest example of what has been termed "High Victorian eclecticism," a kind of Canadian national architectural style (Kalman, 1994). This style is also known informally as "picturesque Gothic revival style," and includes many elements from medieval architecture. The composition of the Federal Parliament Buildings has been described as bold and effective, a tribute to the architects and politicians of the mid-19th century. The Centre Block in particular, as reconstructed in the early years of the 20th century, is a fitting geographic and architectural site for the heart of the Canadian government (Maitland *et al.*, 1992). Following urban rivalries principally among Kingston, Montreal and Ottawa over which town or city would become the capital of the Province of Canada, Queen Victoria, acting on the advice of colonial officials, settled the issue on the last day of December 1857, designating Ottawa as the capital of the Province. The grand scale of the Ottawa Parliament Buildings and their setting is a credit to those of the day. Although conceived as only the capital of the province, following Confederation in 1867 the buildings became available to serve as parliament for the new Dominion of Canada, comprising Ontario, Quebec, New Brunswick, and Nova Scotia. The legislature of the Province of Canada (1841-1867) first sat in Canada's Federal Parliament Buildings on 8 June 1866. In 1916, a fire destroyed the original Centre Block and the Victoria Tower. This paper focusses on the reconstruction of the Centre Block and the Peace Tower which replaced the original buildings, a monumental task that took 12 years to complete. The emphasis in this article is on the exterior stone, the construction history, and recent restoration.

Figure 1 Aerial view of Parliament Hill looking northwest, summer, 1974. The Rideau Canal and locks, completed in 1832, lie immediately to the east; the Chateau Laurier Hotel is seen at lower right on the east bank of the Canal; the Ottawa River is seen to the north. National Air Photo Library, Natural Resources Canada.

Background

Canada's Parliament Buildings are located on an 11.6 ha site near the edge of a 50 m limestone cliff commanding a view over the Ottawa River to the north, and the Rideau Canal to the east (Fig. 1). In 1977 Parliament Hill and all of its buildings were designated as a National Historic Site.

The Parliament Buildings comprise three main "blocks": the south-facing Centre Block with its attached Peace Tower in front and Library at the back (Fig. 1), flanked on either side by East and West blocks. All three face inward to form three sides of a large quadrangle. The eternal flame, built in 1967 to commemorate Canada's confederation, is located on the south side of the quadrangle. The East and West blocks, built between 1859 and 1865, are original structures, as is the Library. The Centre Block and the Peace Tower were reconstructed after the original Centre Block and Victoria Tower, built 1859-1878 (Fig. 2), were burned beyond saving on 3 February 1916 (Fig. 3).

The design for the original mid-1800s buildings was selected from 16 submissions. The winning design, formally identified as "High Victorian Gothic Revival style," was submitted by architects Thomas Fuller and Chilion Jones of Toronto, Ontario (then Canada

Figure 2 The original Centre Block and Victoria Tower, built between 1859 and 1866, were destroyed by fire on 3 February 1916. Photo circa 1885, National Archives of Canada PA 178205.

West). The construction contract was awarded on 27 November 1859 to Mr. Thomas McGreevy of Quebec City, Canada East. Later, at McGreevy's suggestion, the contract was divided, and Messers. Jones, Haycock and Co. of Port Hope, Canada West (Ontario from 1867), assumed responsibility for constructing the Departmental Buildings, now known as the East and West blocks. The original contract price for the construction of the Centre Block and Victoria Tower was $348,500, and for the East and West blocks, $278,810. All buildings were to be completed by 1862. Although the Centre Block was not finished, the Legislature first sat in the new building in June 1866. Costly overruns, caused principally by poor construction management, pushed the completion price to $1,750,720 for the Centre Block, Victoria Tower and Library, and $641,036 each for the East and West blocks (Canada Parliament, 1891).

The Centre Block, reconstructed between 1916 and 1922, is a 6-storey, steel-reinforced stone building, approximately 143 m long by 84 m deep. Although occupying almost the same footprint as the original 4-storey building, it provided 47% additional interior space. Its Modern Gothic Revival design is characterized by features such as **wing towers**, high-pitched **variegated roofs**, pierced by **dormers**, **horizontal courses**, **pointed stone arches** at windows and doors, and carved ornaments (for readers not familiar with architectural terms, a glossary is included as Table 1. Terms defined in the glossary are bold printed throughout the text). The dominant feature of Parliament Hill, the Peace Tower, built between 1919 and 1927, rises 97.5 m in height, replacing the original Victoria Tower (60 m). The design for the reconstructed Centre Block and Peace Tower incorporated some of the most up-to-date building materials and techniques available at the time.

Despite a determined effort to control costs of reconstruction, the final cost of the Centre Block and Peace Tower was $12,379,846.92 (Canada Parliament, undated), almost two and a half times the original estimate of $5,000,000. It took 12 years to complete, 9 years more than estimated.

Since reconstruction, the Centre Block and Peace Tower have undergone constant change, including the addition and rearrangement of interior space, updating of infrastructure, and the completion of ornamentation. They have also suffered the ravages of local industrial pollution, thousands of freeze/thaw cycles, and the effects of road salt. Major renovations and rehabilitation of the structure have been undertaken recently, and more are planned for the near future.

Figure 3 Preparation of Parliament Hill for reconstruction of the Centre Block, 15 August 1916. Workmen with horse teams are removing the last of the rubble from the foundations of the former building. In the middle ground, in front of the Library, another crew is drilling blast holes for foundation excavations. Only the Parliamentary Library remains intact. Its shored up entrance, which connected it to the Centre Block, can be seen beyond the drilling crew. National Archives of Canada PA130624.

Stone for the Original Buildings

Although this article focusses on the building stone of the reconstructed Centre Block and Peace Tower, many of the decisions on the building style and the selection of building materials for the original structures strongly influenced the choice of materials used in their replacement half a century later.

The original 1859 structure (Fig. 2) required the careful choice of building stone, not only of appropriate colour and texture, but also with engineering attributes of strength and durability. It also had to be quarried, cut, and transported at reasonable cost!

The original specification for stone included the use of "native limestone," from Gloucester, Ontario or Hull, Quebec, for the exterior facing and **quoins**, and Ohio Sandstone, from Cleveland, Ohio, for the **dressings** of the windows and doors. However, in 1860, architects Fuller and Jones suggested to the Commissioner of Public Works that the sombre grey of the limestone would not be pleasing. Nepean Sandstone, which is lighter in colour and more durable, was suggested as a better choice, even though the cost would be somewhat higher. Fuller and Jones (27 January 1860) stated:

> We have been most anxious to find some other stone lighter in color and of equal durability, and have for some months been making enquiry and obtaining specimens of the sandstone in the neighbourhood; and as those rocks at Nepean [Ontario] and Templeton [Quebec] appear to us the most suit-

able, we personally inspected them both, and have the honor to lay before you a brief report thereon, together with an estimate of the entire cost incurred by their use. ...

The stone of Nepean is light in color, very hard, but found in layers from three inches to fifteen inches in thickness; the beds are so level and true, and the stones break so readily in a vertical joint, that little or no labor would be required: this we beg to recommend for the **rubble** facing... We find that the extra cost that would be incurred by substituting Nepean sandstone **rubble** masonry for limestone would be $15,400.

In February 1860, William E. Logan, Director of the Geological Survey of Canada, wrote to Samuel Keefer, Deputy Commissioner of Public Works, to discuss the merits of the Potsdam formation (Nepean Sandstone) as follows (Logan, 1860):

...a source of excellent building material. There is no question of the great durability of most of the beds belonging to it, and when such portions of it are selected as are free from iron, there is little doubt of its architectural value. One of the characteristics of the stone, besides its power of resisting atmospheric influences is its capability of enduring great heat without injury. ...the stone could be obtained on the Ottawa [sic] the two most convenient [localities] for the best kind being Presqu'Isle about fifty miles below the city, and the other lots 27, 28, 29 ranges 5 and 6 of Nepean. The stone of these localities would in my opinion be most enduring material.

These recommendations were accepted, and Nepean Sandstone became the prime building material for the Parliament Buildings. Fuller and Jones' estimate represented a premium of $\$0.21/ft^3$ over the use of limestone, based on the greater haulage distance (16 km from the Nepean quarries, as opposed to approximately 5 km from the Gloucester quarries) and the higher cost of quarrying the harder, more durable material. Later, contractors argued that they could not quarry and transport the Nepean Sandstone for the $\$0.21/ft^3$ premium estimated by the architects and requested as much as a $\$0.57/ft^3$ premium to cover their costs.

Table 1 Glossary of architectural terms

Air Towers	· ventilation shafts
Arch	· a form of curved construction, usually masonry, that spans an opening in a wall and distributes the weight above it on the wall or piers at either side
Carillon	· a set of bells sounded by hammers controlled from a keyboard
Dormer	· a window that projects from a sloping roof, with a small roof of its own
Dressings	· masonry or mouldings around windows or the corners of buildings of better quality than the remainder of the facing brick or stone; normally with smooth faces
Dutchman repair	· replacement of damaged portion of a masonry element
Flying buttress	· detached pier of stone, with an arch at the top that provides lateral support for an adjoining wall
Foil	· a curved recess between cusps in gothic tracery; also any of several arcs that enclose a complex design
Gablet	· a gable-shaped stone that crowns a buttress
Gable	· the vertical triangular section of wall between two slopes of a pitched roof
Gargoyle	· a figure that projects from the roof gutter or parapet of a wall or tower and is carved in to a grotesque figure of a human or animal, often a spout to throw rainwater clear of the building
Horizontal course	· continuous horizontal layer of brick or masonry throughout a wall
Lintel	· the horizontal supporting member at the top of a door or window
Parapet	· a portion of a wall that projects above the edge of a roof
Parging	· a wash of plaster or cement applied to hide or stabilize the surface of a wall
Pier	· an upright support, normally square or rectangular in cross-section, and usually of masonry
Pinnacle	· slender point or summit placed on top of a buttress, gable, *etc.*
Pilaster	· shallow pier or rectangular column projecting only slightly from a wall, primarily decorative
Pointed stone arch	· structural element rising to a point, spanning an opening and resisting lateral or vertical pressure
Quatrefoil	· a decorative arrangement of four lobes or leaf-shaped curves, commonly used in Gothic tracery
Quoin	· dressed stones at the corners of buildings, usually laid so that their faces are alternately large and small, usually in a contrasting colour or texture from the rest of the wall
Raking	· loosening and removal of deteriorated mortar, normally by scraping
Repointing	· to scratch out the mortar from the joints of a masonry wall and refill with new material
Rubble	· masonry construction using rough, undressed stones
Shoddy	· a rough undressed building stone
Tracery	· ornamental works in the upper part of a window, screen, or panel, or used decoratively in blank arches and vaults.
Turret	· small slender tower
Variegated roof	· diversity of size and shape of adjacent roof elements
Vault	· arched ceiling or roof of stone, brick, or concrete
Wing tower	· a tower projecting from the main or central part

References: Various sources including, Acland (1972), Fleming *et al.* (1991), Kalman (1994), Macrae and Adamson (1963), and Summerson (1964).

Thus at this very early stage, costs began to escalate. The reconstruction of the Centre Block 50 years later would use sandstone from a number of the same quarries in Nepean Township.

In addition to the local, light grey Nepean Sandstone used for the outer facing of the walls, known as **rubble** or **shoddies**, the following building stones were chosen for the construction of the original building (Page, 1867):

- Ohio Sandstone, a grey/brown relatively soft stone from the Cleveland area, Ohio, used for **dressings**, **gablets**, and **pinnacles**
- Potsdam Sandstone, a reddish sandstone, from the Potsdam area of northern New York State, used for **arches** over the doors and windows
- Slate, both light and dark grey, from Vermont, used for roofing
- Gloucester Limestone from the Ottawa area, used for the interior portions of walls and the **flying buttresses** of the Library, and
- Marble, principally obtained from various sites along the Ottawa River, used in the interior.

Stone for the Reconstructed Buildings

The reconstructed Centre Block had its beginnings with the destruction of the original building. The February 1916 fire started in the Parliamentary Reading Room, ravaged the Centre Block and Victoria Tower, and killed 7 people. Only the Library was spared (Fig. 3). At first it was thought that the facade of the original Centre Building could be saved; however, following investigation of the walls and foundations, it was deemed that this would be imprudent and unsafe. The reconstruction for the Centre Block began almost immediately, and by the fall of 1916 was well underway (Fig. 4).

According to Kindle (1926), the reconstructed Centre Block and Peace Tower display, in their beautiful Gothic lines, good examples of some of Canada's best-known building stones. Nepean Sandstone and Wallace Sandstone were used for the exterior, and Tyndall Limestone for the interior. Ohio Sandstone from the United States was also extensively used on the exterior. In addition, more than two dozen other types of limestones, marbles, and decorative building stones from Canadian and European quarries were used in the reconstruction.

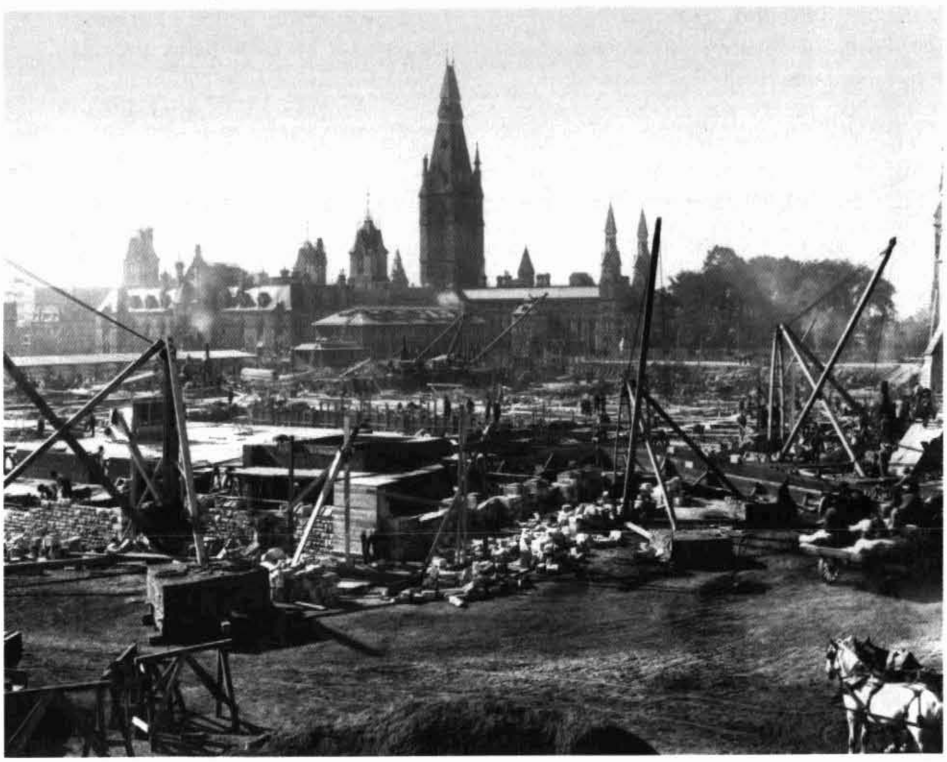

Figure 4 View looking southwest showing the early stages of the reconstruction of the Centre Block. Beyond the construction on the left is the stone cutting shed and to the right the architect's offices. The West Block is in the background. Photo taken 26 September 1916. National Archives of Canada C6361.

The exterior walls comprise: Nepean Sandstone from Ontario for the outer facing; Ohio Sandstone from Ohio for the trim and decoration; and Wallace Sandstone from Nova Scotia for the trim for the light wells, courts, **air towers**, chimneys, and penthouses (Contract Record, 1919).

The most notable change in the building facade of the reconstructed Centre Block is the absence of the red Potsdam Sandstone, which was replaced, for the most part, by Ohio Sandstone. A visual comparison can be easily made between original building stones, as seen in the East and West blocks and the Library, and the newer materials, as seen in the reconstructed Centre Block and Peace Tower.

The principal interior building stone is Tyndall Limestone from Manitoba. This beautiful, warm, vibrant, fossiferous limestone is used throughout the main floor of the building for walls and **vaults**.

In an attempt to avoid the problems experienced with the construction of the original buildings, two general polices were adopted for the reconstruction: the use of Canadian materials wherever possible, and the selection of the lowest bids for materials and services to avoid political patronage. A Joint Committee was struck composed of four members appointed by Prime Minister Borden and four members appointed by the Leader of the Opposition. Its mandate was to control all aspects of the reconstruction and to ensure that cost overruns and labour problems, like those encountered during the original construction, would not be repeated.

Between 1916 and 1921 the Joint Committee met 64 times, voting on resolutions dealing with finances, engineering, design detail and arbitration of contracts. Two of their early decisions included the appointment of Pearson and Marchand as architects and Peter Lyall and Sons Construction Co. Ltd. as contractor. All came with impressive credentials.

John A. Pearson (1867-1940), the principal architect for the reconstructed

Centre Block and Peace Tower, was born in England and educated at the University of Sheffield. Pearson came to Canada in 1888 and joined the Toronto firm of Darling and Curry. In 1908 the firm of Darling and Pearson was formed. Pearson had been responsible for numerous commercial, institutional, and domestic buildings of various design styles in major cities across Canada.

Jean O. Marchand (1872-1936), associate architect for the reconstructed Centre Block and Peace Tower, was born in Montreal and educated at the College of Montreal. He studied architecture at the Ecole des Beaux-Arts in Paris between 1893 and 1903. Marchand designed the Canadian pavilion at the Paris Exposition 1900, and worked on a wide range of public, commercial, educational, and especially ecclesiastical buildings. In his latter years Marchand was invited by the French Government to assist in the planning for the 1937 Paris Exhibition buildings, and was awarded the Legion of Honour by the French Government for his contribution to French art.

Peter Lyall and Sons Construction Co. Ltd., a large and well-known contracting firm based in Montreal, had been engaged in construction projects throughout Canada. Lyall was born in 1841 in Scotland where he learned his trade, emmigrated to Canada in1870, and about 1879 started his business in association with his five sons (Morgan, 1912). One son, William, was in charge of the reconstruction of the Centre Block and Peace Tower. He was also President of the Wallace Sandstone Quarries Co., the suppliers of both Tyndall Limestone from Manitoba and Wallace Sandstone from Nova Scotia.

GEOLOGY OF THE BUILDING STONES, CENTRE BLOCK AND PEACE TOWER

Exterior Stone

The formation, age, description, source, and use of the exterior building stones in the reconstructed Centre Block and Peace Tower are summarized in Table 2. The primary building stones are discussed below.

Nepean Sandstone

Nepean Sandstone is the principal material used in the exterior walls of the reconstructed Centre Block (Fig. 5). This white to cream coloured, almost pure quartz sandstone, was obtained from the township of Nepean, south east of the present-day City of Kanata, Ontario, approximately 16 km west of Parliament Hill. Casual observation of this material, *in situ*, can be seen in a road cut along Highway 417 on the height of land just east of the City of Kanata.

Upper Cambrian sandstones are exposed in the Frontenac Axis, which extends from Ottawa southward to the Kingston-Brockville area (Wilson, 1946) and into upstate New York. In the south, the sandstone is generally known as Potsdam Sandstone, taking its name from the town of Potsdam, New York. Its colour ranges from white and buff, to light shades of salmon pink, purple, dark rose, and, less commonly, brick coloured. The pink and red varieties historically have been highly sought after as a building stone for commercial and residential buildings. In the north, the sandstone that lies to the west of Ottawa is known as Nepean Sandstone. It is white to cream in colour and is harder than its southern counterpart. Parks (1912) considered the material from Lot 6, Concession II, Ottawa Front, Nepean Township as typical and described it as follows:

> The beds on this and on the adjoining properties are exposed on a gentle hill rising above the surrounding farmland. The dip is northward at a low angle [nearly flat lying in most locations]..... Joints cut the beds north and south and east and west and are rather irregularly developed. Blocks can sometimes be obtained 4 to 6 feet [1.2-1.8 m] long but never more than 2 feet wide [60 cm]. The joint planes are almost always covered with a brown skin of iron oxide; this skin must be split off, if it is desirable to use the joint face for the exterior of a block in a building. Failure to do this has injured the appearance of certain buildings.....
>
> The stone: No. 216. Although commonly called white Nepean sandstone, this example shows a distinctly grey colour. ... There is no appreciable change in colour on treatment with carbolic acid in water. The stone is composed of irregularly shaped quartz grains embedded in a calcareous cement of which there is a considerable quantity.

The physical characteristics are:

Specific gravity	2.613
Weight per cubic foot	153.504 lbs.
Pore space	7.22%
Ratio of absorption	2.93%
Coefficient of saturation	0.21
Permeability	4.87 c.c./in.^{2}/h
Crushing strength	22,032 lbs./in.^{2}

Reports prepared during the reconstruction cite problems with the quality of the Nepean Sandstone to the point where some stone was rejected. Observations on the construction site suggest that there was considerable variation in the quality of the building stone, varying from the most durable quartzitic material to relatively vulnerable stone that may have been quarried from beds where the cementing material was partly calcareous, argillaceous or ferruginous (Keith Blades, personal communication, September 2000).

Dick Williams, a Welshman who came to Canada in 1902, opened a small quarry in the Nepean formation on the farm of his father-in-law (Fig. 6). The two began making paving stones in 1912 and in 1916 they were joined by a young Scot, Archie Campbell, a recently apprenticed quarryman (Jennie Hutchinson, daughter of Dick Williams, personal communication, July 2000).

According to Campbell (*in* Goldblatt, 1949):

> Our first order came from Peter Lyall Construction Company for 1,000 tons of sandstone all for the Parliament Buildings. When we got the parliament job there were several hundred men on the job and they just gobbled up the stone. We couldn't get the stone out fast enough ... Stone was hauled up to the building site by teams of horses, struggling along poor roads with six-ton loads. Each team could make but one trip a day.

To meet the demand, Campbell imported many quarrymen and stone cutters from Scotland where the trade still flourished. The Campbell Quarry, as it came to be known, supplied much of the stone for the Centre Block and all of the stone for the Peace Tower (Burnett, 1962). The quarry continued operation under various owners until September 1962, when the National Capital Commission expropriated the land for part of Ottawa's Green Belt. Offices, laboratories and experimental sites of Natural Resources Canada now occupy the quarry and surrounding property.

Nepean Sandstone has been widely used in government, office, and residential buildings and numerous churches in the Ottawa area. Well-known buildings include the Victoria Memorial Museum (1912; now the Museum of Nature), Royal Canadian Mint (1908), Public Archives, (1907; now the War Museum), Royal Observatory at the Central Experimental Farm (1903), Confederation Building (1930), Connaught Building (1913), Langevin Building (1889), and the Nepean Town Hall (1896).

Sourcing and the evaluation of replacement stone for the recent rehabilitation of the Parliamentary Library, by the author and others, has led to the renewed sampling and testing of material from the old quarry, and discussions of the original quarrying operations with a number of local "old time" residents.

Ohio Sandstone

Ohio Sandstone, also referred to as "Ohio Stone" or "Cleveland Stone," was used in both the original and reconstructed Centre Blocks for trim on the windows and doors (Fig. 5). In the reconstruction, some material was salvaged and recut on site. New stone was purchased from the same quarry as the original in Ohio (David Tyrrell, former president of the American Stone Corp., personal communication, April 2000).

Ohio Sandstone is part of the Berea formation of Mississippian age. Berea sandstone has been quarried in Ohio since the early 1800s and its use as a building stone in North America is widespread. It is a medium to fine-grained, clay-bonded, quartz sandstone (Pepper *et al.*, 1954) with a fairly uniform composition, and silica usually in excess of 90%. The colour is normally a blue-grey, however, near-surface rock may be buff or yellow. The buff colour in some localities extends to a depth of 9 m. When exposed in an exterior wall the blue-grey stone gradually changes colour to grey, and finally to buff, owing to oxidation (Brownocker, 1915). The buff stone for the Centre Block and Peace Tower was quarried close to Birmingham, Ohio, and shipped by rail from Wakeman, Ohio. Stone currently taken from this quarry is known in the trade as "Birmingham Buff Sandstone." It is normally massive with no apparent bedding planes; however, in a few places, beds may be defined by thin shale partings. Vertical breaks in the rock are less common than horizontal breaks. Notable Canadian buildings containing Ohio Sandstone include the Bank of Canada in Montreal, Bank of Commerce

Table 2 Principal Exterior Building Stones of the Centre Block, Peace Tower and Library

STONE	FORMATION	AGE	DESCRIPTION	SOURCE	PRINCIPAL USE
Nepean Sandstone	Nepean (considered to be correlative with Potsdam)	Cambrian/ Ordovician	Medium-grained, mottled white to cream coloured, almost pure, quartz sandstone with irregular rust spots	Nepean, Ontario Various quarries, approx. 16 km west of Parliament Hill	Principal stone for the walls of the Centre Block, Peace Tower and Library
Ohio Sandstone (Birmingham Buff Sandstone) (Berea Sandstone)	Berea	Lower Carboniferous	Coarse-grained, gritty, bluish-grey to buff, porous sandstone	Original source quoted as Wakeman, Ohio (see text for explanation)	Trim around doors and windows, decorative elements dressings, **pinnacles**, **turrets**, and towers
Wallace Sandstone	Boss Point	Upper Carboniferous	Medium-grained, buff sandstone, very similar in appearance to Ohio Sandstone	Wallace, Cumberland Co., Nova Scotia	Archway of the Peace tower, trim for doors and windows on the interior courtyards, **air towers**, light wells, chimneys, and penthouses. Not easily distinguished from Ohio Sandstone when weathered
Portage du Fort Marble	Grenville	Precambrian	Massive white dolomitic marble	Portage du Fort, Pontiac Co., Quebec	Cornerstone
Stanstead Granite		Devonian	Medium- to coarse-grained grey granite	Beebe, Quebec	Steps of the Main entrance and **gargoyles** at the observation level of the Peace Tower
Potsdam Sandstone	Potsdam	Cambrian/ Ordovician	Pink, coarse-grained quartz sandstone	Malone, New York	Window and door trim for the Library (1860s construction)
Gloucester Limestone	Ottawa	Ordovician	Limestone with interbedded shale	Gloucester, Ontario approx. 5.5 km east of ParliamentHill	**Flying buttresses** on the Library (1860s construction)

in Winnipeg, and numerous buildings in Toronto.

ASTM test data for the Birmingham Buff Stone are:

Compressive strength .... 79.8 Mpa
Modulus of rupture .... 8.1 Mpa
Specific gravity............................ 2.153
Absorption 5.8%
(provided by The American Stone Corporation, 1999).

Wallace Sandstone

Wallace Sandstone was not used on the original Centre Block; however, in an effort to reduce costs for the reconstruction, considerable effort was made to use a Canadian source of sandstone. It was decided that Wallace Sandstone from Nova Scotia, which is very similar in appearance to Ohio Sandstone, would be used externally for **air towers**, chimneys, penthouses, the **quatrefoil** in the Peace Tower, and for carved blocks and trim on windows and doors on the interior court elevations. Ohio Sandstone was retained for most of the other exterior details. Wallace Sandstone may have been used elsewhere, but lack of detailed records and heavy soiling make it difficult to identify positively.

This Upper Carboniferous, grey and olive sandstone from the Boss Point Formation of the Cumberland Group is from the Wallace area, Cumberland County, Nova Scotia. It has been widely used as a building stone since the early 1800s, and is highly prized because of its colour, texture, and ease of carving. Although this stone has been quarried from a number of localities, the largest, most productive, and the only one currently in production is that of the Wallace Stone Company. The level of activity at the quarry in the early part of the 20th century was considerable (Fig. 7). This quarry was the source of the stone used in the Centre Block and Peace Tower. According to Parks (1914a), the deposit was discovered while digging postholes, and was initially quarried for flagstone. He described the beds as being almost horizontal. Two well-defined vertical joint systems, with a spacing from 3 m to 6 m, run at approximately right angles to each other, facilitating quarrying operations. He described the sequence of beds in the north east corner of the property as follows (Parks, 1914a):

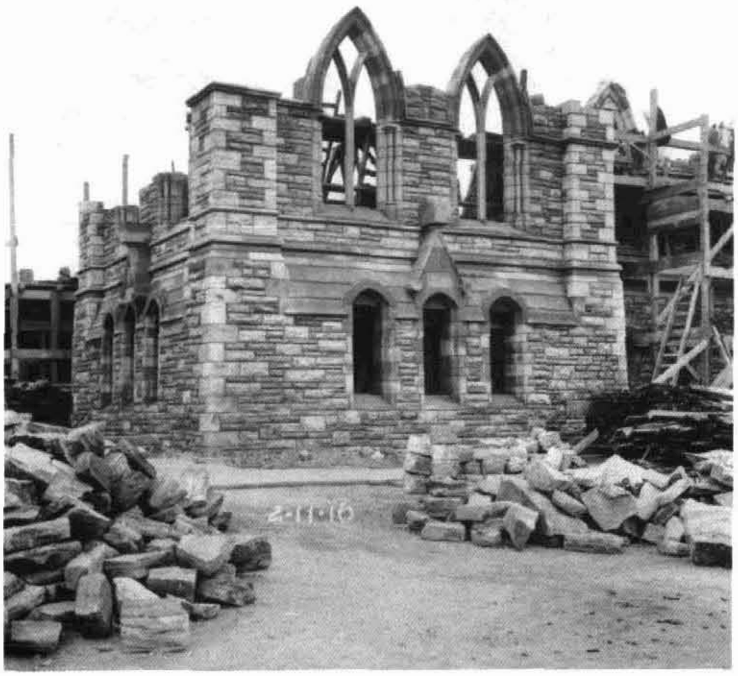

Figure 5 Detail of the partly completed masonry of the south facade of the Centre Block, November 1916. The **quoins** and **shoddies** are composed of Nepean Sandstone and the window **arches**, **lintels** and **gable** are of Ohio Sandstone. The rectangular block above the small central **gable** atop the middle window, ground floor, was later carved in the form of a **gargoyle**. National Archives of Canada, PA205986.

Figure 6 Quarrying operations in the early 1900s in the Ottawa Valley were similar to those seen here at the Stewart Quarry, Rockland, Ontario, 1898. GSC collection, National Archives of Canada, PA51315.

20' (6 m) Stripping. Soil and thin hard shaly stone;
6' (1.8 m) Heavy yellow bed;
9' (2.7 m) Heavy yellow bed. Thin layer of shale;
6' (1.8 m) Bed of grey stone (Blue);
20' (6 m) Grey stone in heavy layers.

The Wallace Quarry has produced three colours of stone. The greatest volume has been a medium to dark olive-green, fine- to medium-grained, massive sandstone. The average thickness of the quarried unit is 12 m. It overlies a fine- to medium-grained, blue-grey sandstone with an average thickness of about 3 m. A light, olive-green sandstone has also been produced from small pockets on the northwestern sides of the quarry.

Parks (1914a) described the mineralogy of Wallace Sandstone stone as follows:

> ...the stone is seen to be made up of fairly uniform quartz grains of about 0.25 mm in diameter, and feldspars of about the same size in far less abundance. The grains are rather rounded in outline, and are fitted closely together with only a small amount of greenish-yellow cement of an argillaceous character. Although the feldspars show decomposition, there is, on the whole, very little indeterminable material, as little is to be seen except quartz, feldspars and cement. Mineralogically, there is little to distinguish the "blue stone" from the grey stone.

Physical properties of the Wallace Sandstone are:

Compressive strength .... 11,154 psi to14,759 psi
Absorption .... 4.0% (24 hours immersion)
Saturation coefficient 0.644
Unit weight (dry) .... 141.0 lb./ft.^{3} to 145.2 lb./ft.^{3}
Porosity 14.3%
Freeze/thaw .... 50 cycles, no failures
Average weighted loss at end of cycling 0.06%
(National Research Council, 1967).
Note: These test results are generally similar to those of Parks (1914a).

In addition to the trim and carvings on the Centre Block and Peace Tower and the Victoria Museum in Ottawa, Wallace Sandstone has been used widely throughout Canada. Many cities throughout the Maritimes have made use of this stone for their public buildings, one of the most noteworthy being the Provincial Building in Halifax. Considerable volumes of the stone have also been used for buildings in New York and Boston.

The Twice-laid Cornerstone

The white marble cornerstone from the original Centre Block was recovered from the debris of the 1916 fire and re-laid, approximately 30 m further east, at the extreme northeast corner of the new building, by the Duke of Connaught, Governor General of Canada, on 1 September 1916. It is interesting to note that it was his brother, King Edward VII, then the Prince of Wales, who laid the same stone exactly 56 years earlier (Fig. 8).

The cornerstone is a coarse-grained, slightly banded dolomitic marble quarried near the village of Portage du Fort in Pontiac county, Quebec, about 100 km northwest of Ottawa. It was quarried from one of the numerous exposures of Grenville marble, which are common in the area.

A hand specimen of this marble was described by Parks (1914b) as follows:

> ... a pure white dolomite unmarred by any flaws except the occasional occurrence of minute yellowish specks. ... The grain is coarse with crystals up to 10 mm in diameter. The corrosion test produces no changes apparent to the naked eye but slight pitting of the surface may be seen with a strong lens.

After listing the physical properties and the results of strength, corrosion, and absorption tests, Parks commented that the stone is very durable and little affected by freeze/thaw. Calculations made from the chemical analysis indicate 55.12% carbonate of lime and 43.07% carbonate of magnesia.

Interior Stone

More than two dozen types of building stone, decorative stone, and marble were used in the interior of the Centre Block and the Peace Tower, many from Canadian sources (Table 3). The selection of these materials was carefully considered. Deliberations between the architects and the Parliamentary Committee were often protracted. Many visits to quarries and reports of experts were required.

Following the principle of using only Canadian materials proved to be difficult in many instances. Acquiring Canadian stone and marble of sufficient quality and quantity was a problem, and compromises had to be made. For example, the corridors of the top floor of the Centre Block are lined in a rose red limestone that was originally intended for the Senate Chamber: on delivery, however, this limestone proved unsuitable, as insufficient quantities were available (Public Works and Government Services

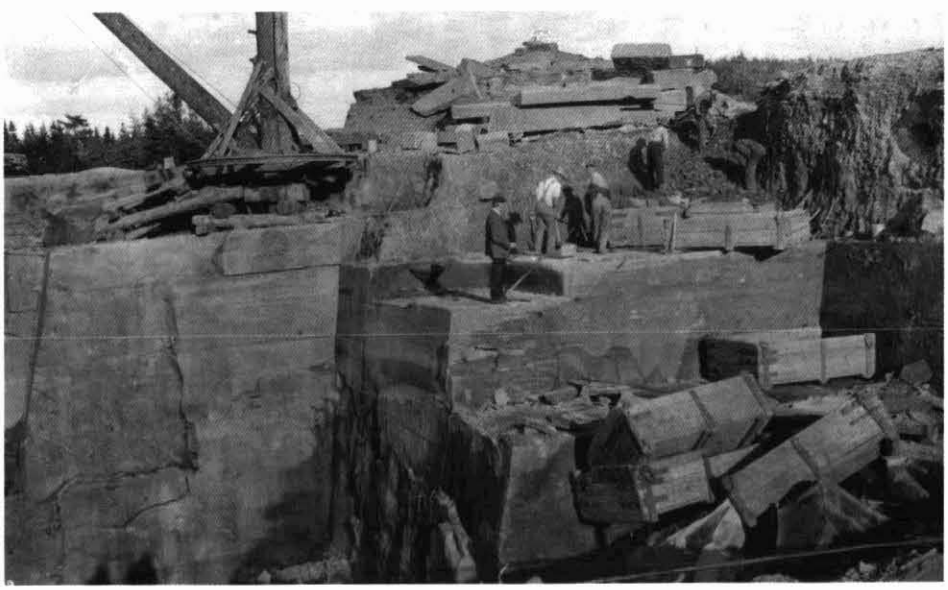

Figure 7 Quarrying sandstone at the Wallace Quarry, Nova Scotia. This stone was used in part as a replacement for Ohio Sandstone on the reconstructed Centre Block and Peace Tower. J. Keele, 1909, Geological Survey of Canada.

Canada (PWGSC), 1997).

The most elaborate rooms of the Centre Block are the chambers of the House of Commons and the Senate. Their walls are lined with Tyndall Limestone. Those in the Senate Chamber are elaborately carved in Gothic design.

Tyndall Limestone

Tyndall Limestone, the principal interior building stone used throughout the main and second floors for walls, **piers**, and **vaults**, is a beautiful, warm and vibrant fossiliferous limestone from Manitoba. This Upper Ordovician stone is a thickly bedded (60 cm to >100 cm), mottled dolomitic limestone, mined from the Selkirk Member of the Red River Formation. It is known to have been used as early as the 1830s for construction of Lower Fort Garry, Manitoba, and has been a popular building stone in Winnipeg and throughout Canada since that time. It is currently exported worldwide as a facing stone for both exterior and interior use. The main quarries, located 50 km northeast of Winnipeg, have been in continual use since 1898. In addition to being used in the Federal Parliament Buildings, it is the principal stone used in the Manitoba and Saskatchewan legislative buildings.

The stone is known to crop out for a considerable distance northward along the shore of Lake Winnipeg and southward into the United States where it is less mottled, harder and more difficult to work. The prime, mottled, fossilifer-

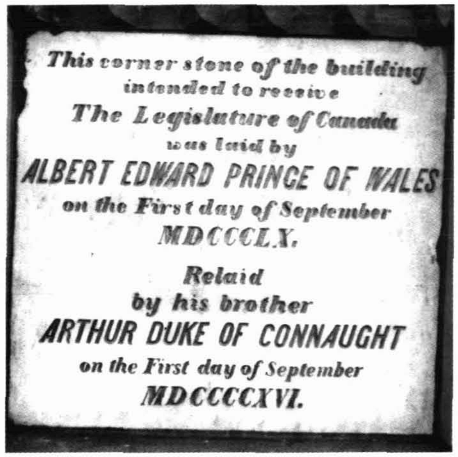

Figure 8 The twice-laid corner stone of Canada's Parliament Building. Photo *ca.* 1925. National Archives of Canada PA 34435.

Table 3 Interior Building and Decorative Stone of the Centre Block and the Peace Tower

STONE	PRINCIPAL USES	SOURCE
Tyndall Limestone	· Walls of Corridors, entrance halls, main and first floors Commons and Senate Chambers; Confederation Hall and Hall of Honour	Garson, Manitoba
Bath Stone	· Commons Railway Committee Room	Bath, England
Missisquoi Bolder Grey Marble	· Floors of Corridors, Entrance Halls and Stairs	Philipsburg, Quebec
Missisquoi Verte Gris Marble	· Walls of Corridors, fourth and fifth floors	Philipsburg, Quebec
Missisquoi Black Marble	· Border and base on floors of Main Corridors	Quebec
Hoidge Light Pink Cloud Marble	· Walls to Corridor, sixth floor	Bancroft, Ontario
Hoidge Dark Pink Cloud Marble	· Border to Corridor, sixth floor	Bancroft, Ontario
Grand Antique Marble	· Columns at entrance to Main Dining Room and Mantles	Vermont
Rose Tavernelle Marble	· Balustrade at Commons entrance Hall, Main Floor and seats over radiators in corridors	Italy
Vert Antique Marble	· Border of Main Corridors	Roxbury, Vermont
Red Verona Marble	· Columns in Senate Entrance Hall and Senate Chamber	Italy
St-Anne Marble	· Columns in Memorial Chamber	France
Belgian Black Marble	· Base in Memorial Chamber and Clock Cases	Belgium
Chateau Gaillard Stone	· Walls in Memorial Chamber	France
Hoptonwood Limestone	· Walls in Memorial Chamber	Darbyshire, England
Peerless Indiana Limestone	· Senate Chamber, Commons Chamber, and Foyer	Bedford, Indiana
Pink Tennessee Marble	· Walls and floors in lavatories	Knoxville area,Tennessee
Cedar Tennessee Marble	· Safes, Sills and Backs to Radiators	Knoxville area, Tennessee
Stanstead Granite	· Sidewalks and Gargoyles on Tower	Beebe, Quebec
Tinos #2 Serpentine	· Circular Border, Main Entrance Hall	Tinos, Greece
Battlefield Stone	· Floor of Memorial Chamber	France and Belgium
Black and Gold Marble	· Mantles	Belgium
Blanco Italian Marble	· Counter tops and Fronts in Serving Room	Italy
Red Granite	· Columns, Entrance to Library	St. George, New Brunswick[1]
Windsor Green Syenite	· Columns, Confederation Hall and Hall of Honour	Windsor, Vermont[2]

Modified from "List of Stone and Marble Generally Used in the New Parliament Building at Ottawa"
Attributed to architect John Pearson and certified correct by A. Keefer, May 1941

[1] Some documents indicate source to be Gananoque, Ontario

[2] Some documents indicate source to be Iberville, Quebec

ous, world-famous Tyndall Stone is only mined at Garson, Manitoba (Wilkins, 1986). Kendall (1977) attributed the unique mottling to the differential dolomitization of tubular cavities that have been identified as the burrows of boring organisms.

Two colour phases are recognized: a lighter, buff-coloured stone, characteristic of the upper beds; and a blue or grey stone found at depth. The lighter colour of the upper material is attributed to weathering. The stone parts easily along bedding planes, which facilitates quarrying. An unusual feature of Tyndall Limestone is that it performs well both when placed on edge and on its bedding plane (Pugh, 1935).

Confederation Hall

The main interior feature of the Centre Block is Confederation Hall. It is an octagonal space at the crossroads of the building, with the Commons Chamber lying to the west and the Senate Chamber to the east. The Hall of Honour to the north leads to the Library of Parliament (Fig. 9).

The most striking feature of Confederation Hall is its central column, which expands into an umbrella-like vault with eight radiating ribs, each joining a clustered pillar at the perimeter of the hall, and carved from mottled Tyndall Limestone (Fig. 10). The massive central column represents the central government, and ten perimeter pillars, made of stunning Windsor Green Syenite from Vermont (actually a nordmarkite; DeGrace, 1982) represent the provinces. A carving of Neptune and his sea lions, symbolizing Canada's maritime commerce, encircles the base of the central column.

The floor surrounding the column is inlaid with decorative stone, beginning with a stylized mariner's compass with its sixteen points executed in Vert Antique Marble (actually a serpentine) from Philipsburg, Quebec, radiating from the column. An intricate fracture pattern within the dark green serpentine is filled with white calcite. Missisquoi Black Marble is placed between the points of the compass. A wide band of white travertine flagstones from Italy surrounds the compass and picks out the dark points. The sea is represented by a wavy art deco band of Tinos #2 serpentine from the island of Tinos, Greece. This dark serpentine is inlaid between two circular bands of Missisquoi Bolder Grey Marble from Philipsburg, Quebec. An outer circular border of Vert Antique Marble completes the elements of this striking composition (Fig. 10).

The remainder of the floor of Confederation Hall is made mostly of bands of Missisquoi Bolder Grey Marble flagstones, its fine joint pattern adding a distinctive linear pattern to the floor's surface. The Missisquoi flagstones are bordered by a dark-green, richly veined marble and an outermost border of black marble.

CONSTRUCTION OF THE NEW CENTRE BLOCK

Cutting, preparation, and placement of the various exterior and interior building stones were the largest and most prominent construction activities. More than

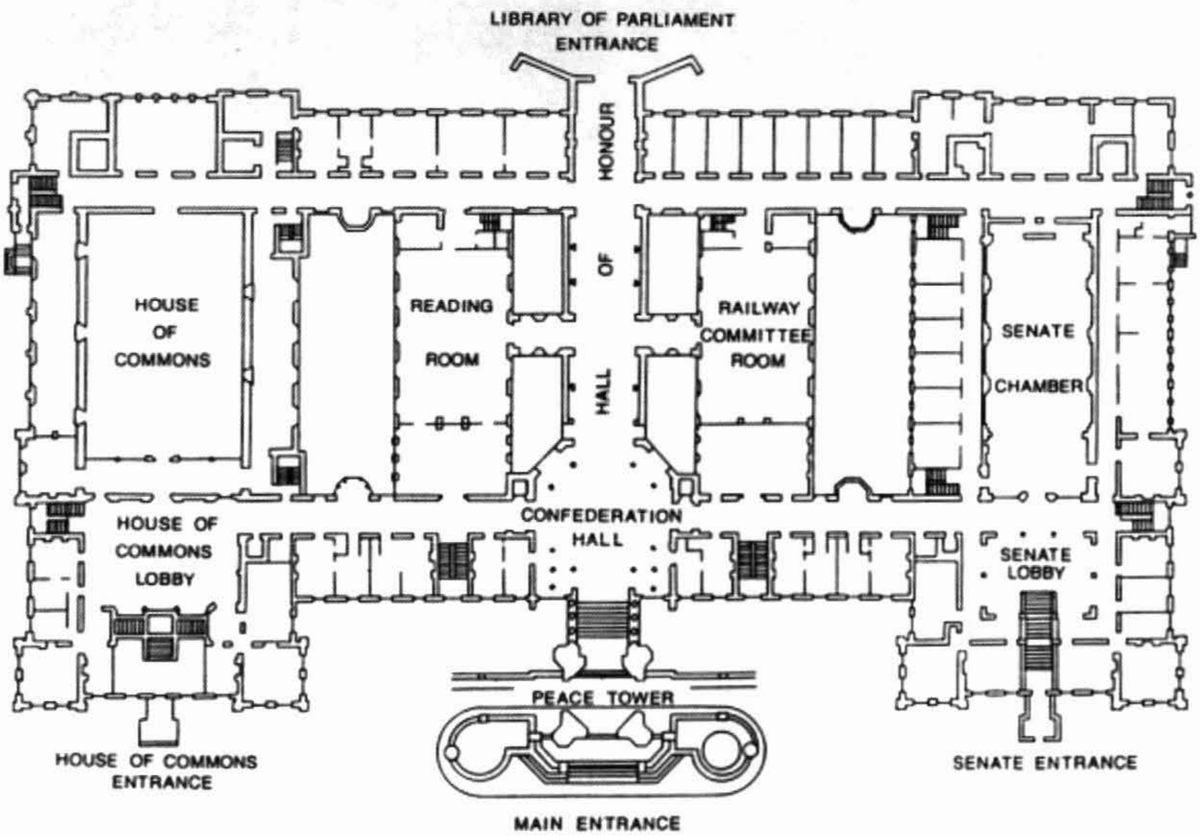

Figure 9 Generalized plan of the main floor of the Centre Block, modified from plan in PWGSC (1994).

300 men were employed, and in 1920 they were paid $1.00/h compared to $0.85/h for carpenters and plasterers and $0.60/h for skilled labourers (Lyall and Sons, 1920). Special facilities along Sussex Street, east of the Rideau Canal, were constructed to cut and prepare the building stones (Fig. 11). According to John Pearson these facilities were the most complete and efficient of their kind in Canada for the finishing of stone and marble (Pearson, 1918). Over a period of 6 years, 16,000 tons of Nepean Sandstone for the exterior, at least 175,000 cubic feet of Tyndall Limestone for the interior, and considerable quantities of other sandstones, limestones, and marbles were handled in the workshops (Dubé, 1989).

Facilities

A machine shop, 150 x 70 feet (45 x 21 m), contained all the sawing equipment including: a circular saw, capable of cutting at the rate of 3.5 inches per minute; three gang saws carrying up to 16 blades using sand and crushed steel as a cutting abrasive, with a cutting rate of 3 inches per hour; and a reciprocating diamond saw with a feed rate of 3.5-18 feet per hour (1.06-5.45 m/h). Three planing machines were required for mouldings. One with the capability of circular work up to 16 feet (4.8 m) radius was used for the rough cutting of the quarry blocks prior to hand tooling. Five tool-smiths were employed to keep the tools adjusted and sharpened, and to reset the diamonds in the saw teeth. In the yard, three 15 ton (13.6 tonne) steel guy derricks and two 10 ton (9 tonne) stiff-leg derricks were used to unload the rough stone blocks, which averaged 10 tons (9 tonnes) each.

In the adjoining finishing shop (600 x 50 feet; 181 x 15 m) only hand labour was used to cut, polish, and finish the stone. The stone cutters (an average of 200 for nearly 6 years) worked in three rows the full length of the building. Between the rows of men were two narrow gauge tracks for hand trucks supplying rough blocks and taking away finished stone (Contract Record, 1919; this article contains excellent photos of these buildings and their interiors showing equipment and men at work).

In addition to the above facilities, a stone shed was erected on the building

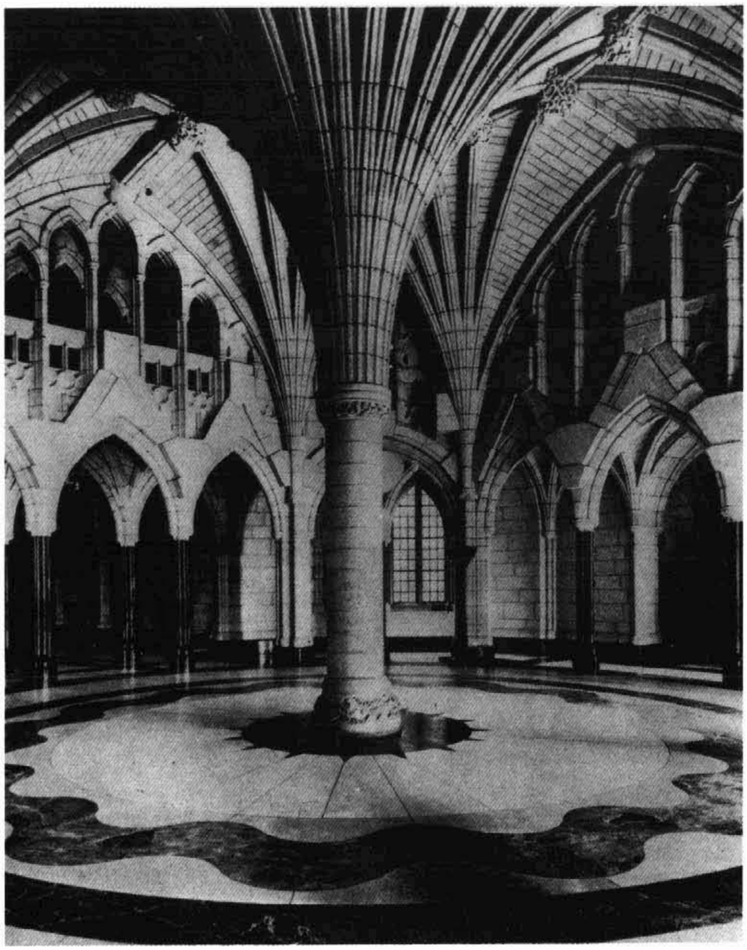

Figure 10 Confederation Hall showing the central column and fan vault, and the detail of the marble floor. National Archives of Canada, PA 022430.

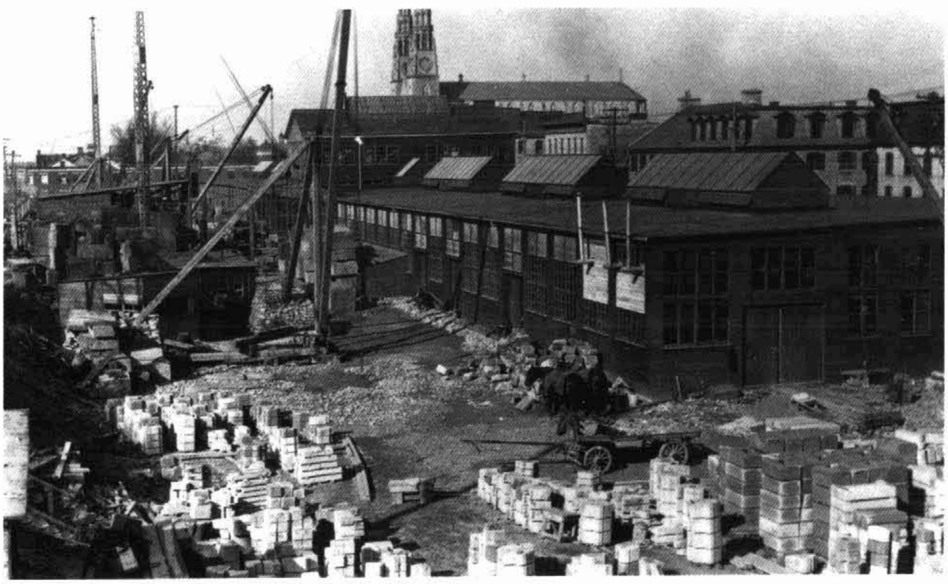

Figure 11 The stone cutting shop on Sussex Drive, fall, 1916. Three derricks used to move the stone were located in the adjacent yard. This site is now occupied by the recently completed (2000) American Embassy. Notre Dame Basilica can be seen in the background. Samuel J. Jarvis collection, National Archives of Canada PA 24996.

site, directly in front of the Centre Block. There, thousands of cubic feet of buff Ohio Sandstone as well as the Nepean **shoddies** that faced the walls of the original building were reclaimed and recut (Pearson, 1916).

Operations

The routine operations started with the architect's department, which would supply the drafting room with scale drawings showing elevations and floor plans. The draftsmen translated these into diagrammatic perspective sketches and then to full-size designs from which full-size patterns were made for each stone. An elaborate reference system was developed to identify and number each individual stone within any elevation or floor plan (Contract Record, 1919). As both the stone and machine shops were erected solely for the construction of the Centre Block and Peace Tower, these facilities were dismantled following Centre Block and Peace Tower completion. Today the site is occupied by the recently constructed American Embassy.

Difficulties

The demands of the 1914-1918 Great War slowed preparation of building stone. Many stone and marble shops throughout the country were closed, and stone cutters were in extremely short supply. Work on the Centre Block continued sporadically, depending on the availability of material and labour. The demand for stone for the reconstruction was so great that it taxed all existing stone and marble shops to the limit of their capacity (Dubé, 1989).

Negotiations for the purchase of 16,000 tons of Nepean Sandstone started in July 1916. In order to complete the Centre Block by the December 1918 deadline, contracts were signed with seven different firms. Final deliveries, however, were only received after a bonus was granted to the subcontractors, and special trains were dispatched to the quarries in Nepean to bring the stone to Ottawa (Pearson and Marchand, 1920).

A similar shortage occurred for the supply of interior building stone. In all, nine firms were engaged to supply the necessary materials. Of these, four contracts had to be cancelled and of the others, only two were still making deliveries to the site in 1920. The stone cutting alone for the Centre Block took 6 years instead of the 2 years originally estimated (Dubé, 1989).

Added to these problems was the escalation of the cost of materials, which had increased 144% between the start of construction in 1916 and the summer of 1920 (Pearson, 1920). Similarly, wages of tradesmen had risen 100% during the same period (Lyall and Sons, 1920). By 1920 the extra labour, materials, and subcontract costs amounted to $2,105,668.

The unfinished Centre Block was officially opened on 26 February 1920 (Fig. 12).

Figure 12 The nearly completed Centre Block, in 1919. Construction of the Peace Tower had not been started at this time. The stone masons' shed and the architect's site office can be seen on the left in front of the building. W.J.Topley, National Archives of Canada PA 12925.

The Peace Tower

Built between 1919 and 1927, the tower was named after the original Victoria Tower, but was renamed the Peace Tower in 1933 (Gowans, *in* Marsh, 1999, p. 1763). Historically, towers on government buildings had been a source of considerable embarrassment to the Government. The tower at the Victoria Museum in Ottawa had to be demolished in 1916, only 6 years after construction, because of severe differential settlement problems (Crawford, 1952), and the Laurier Tower on the West Block collapsed during construction of the north wing (Anonymous, 1906). The collapse was attributed to the thaw, in April, of frozen mortar that was placed during the winter months (Ken Elder, Conservation Architect, PWGSC, personal communication, October 2000).

John Pearson, the project architect, had considered designs for a tower and had produced several sketches. By the fall of 1919, however, only the foundations had been built. In April 1920 Pearson presented, to the Joint Committee, a design concept for the tower. Although given permission to proceed, the **carillon** was not approved, but space for it was allowed so that it could be installed at a later date. Pearson's concept was a free-standing bell tower of about 90 m, 30 m taller than the previous Victoria Tower. It was to include a Memorial Chamber that would pay tribute to Canadians who had fallen in the Great War. Pearson also had the idea of incorporating stone from the battlefields of various European countries to commemorate the sacrifices of Canadian soldiers in the Great War. This would be a monument to peace. Although given permission by the Joint Committee to visit Europe, he was not authorized to "contract any liability on account of the Committee" (Canada Joint Committee on Reconstruction of the Parliament

Building, 1921). The initiative in approaching the governments of France, Belgium, and England was entirely Pearson's. He undertook this as a private citizen with no authority from the Canadian government. He travelled to Europe in the summer of 1921, receiving the offer of gifts of all the stones necessary to complete the floors, ceilings, and walls of the Memorial Chamber. Unfortunately, Pearson quit the project in December 1921, because of a disagreement over outstanding professional fees.

Following Pearson's departure, the Department of Public Works took charge of the construction of the tower, then at the 46 m level (Fig. 13). It remained at this level for the next 2 years while claims for additional fees from contractors and architects were being disputed. Fortunately, Pearson was retained under a new agreement, to design and supervise the completion of the tower. His plans and estimate of $546,171 to complete the tower were approved in January 1924.

The protracted delays and technical problems were a source of embarrassment to the government of the day. The stone-cutting plant had been on the site since 1916, and the donated stone had been received from the various European countries. There was fear that the already erected sandstone was darkening and weathering, and that the newly erected unweathered stone would..."stick up like a sore thumb" (Canada, House of Commons, 1924b). In addition "streams of [rain]water flowed through the front of the Confederation Hall leaving water marks on the stone" (Canada, House of Commons, 1924a). By the fall of 1924, 27 m had been added to the tower, bringing it to 74 m, and by the end of 1925 the reinforced concrete spire was finally completed and covered with copper.

The tower was constructed of stone and cement without any supporting steel, except for floors. The construction involved two teams of stone masons who worked in alternating shifts: one team putting up a course of stone and the other backing it up with a course of concrete (Dubé, 1989). As work continued on the interior, the temporary shops and most of the stone shop on Sussex Street were removed, and in May 1927, the **carillon** bells arrived from England and were installed.

Although the Memorial Chamber was officially opened twice, on 1 July 1927 and again on 11 November 1928, it was not until December 1928 that the work was finally completed and the public allowed access.

The Centre Block and the Peace Tower were finally completed after 12 turbulent years (Fig. 14). As noted by Gowans (Gowans, *in* Marsh, 1999, p. 1763), these buildings, along with the earlier East and West blocks, present one of Canada's most visually striking and historically remarkable building complexes.

PERFORMANCE AND REHABILITATION OF EXTERIOR BUILDING STONE

Examination of the exterior of the Centre Block in 1994 indicated that the condition of the masonry ranged from good, in the central field of the exterior walls, to dangerous in the **turret** tops and chimneys.

Damage was attributed to earthquake activity, penetration of water into open joints and subsequent freeze/thaw activity, inappropriate or poor maintenance activities, use of the inappropriate mortars, and a misunderstanding of the reasons for deterioration. Damage due to de-icing salts at the entrance areas and the unavoidable problems of stone pore clogging from atmospheric pollutants were exacerbated by the building's structural details (PWGSC, 1994).

Cumulative effects of seismic loadings were determined to have been detrimental to masonry elements above the roofline (**turrets**, **parapets**, chimneys and **air towers**). The most significant seismic events to affect the Ottawa area since the construction of the Centre Block and Peace Tower occurred in 1925 and 1944 with a Modified Mercalli intensity of V, and in 1924, 1935, 1983, 1988, 1990 and 1994 with an intensity of IV (M. Lamontagne, seismologist,

Figure 13 Stone masons at work on the Peace Tower, 4 June 1921. Note the concrete forms and the derrick used to lift and place the stone. The photo was taken from the almost completed Centre Block. The temporary building in the right foreground is the architect's office. The West Block can be seen in the background. National Archives of Canada, C38750.

GSC, personal communication, October 2000). Elements that were constructed of unreinforced masonry and were unrestrained laterally were found to be cracked and unstable (PWGSC, 1994). Frost action in water-soaked open joints exacerbated the problem. It was recommended that these elements, as well as failed or deteriorated elements below these structures, be dismantled and reconstructed (Blades, 1994).

Deterioration of the exterior stone generally was related to one or a combination of the following: soiling, crystallization of soluble salts, water ingress and the effects of freeze/thaw, and the effects of de-icing salts. The main problem areas are associated with zones of saturation and drying (PWGSC, 1994). Zones of saturation are most often associated with projecting elements of the building, while zones of evaporation are adjacent protected elements. In addition, lower courses of stonework at entrances exhibit extreme deterioration due to the use of de-icing salts.

Soiling, caused by atmospheric pollutants in the form of nitrates and sulphates absorbed in rainwater, forms a heavy crust on the stone, especially on projecting surfaces and sculptural details, and inhibits normal moisture migration through the stone (Fig. 15). When this moisture freezes near the outside surface of the stone it expands, building up stresses which cause exfoliation of the surface (Keith Blades, personal communication, September 2000). Although sulphate pollution has diminished with the removal of a paper mill formerly situated on the Ottawa River just upstream from Parliament Hill, carbon dioxide pollution has increased. Silica-bound atmospheric dirt is particularly noticeable on the Ohio Sandstone.

Salt crystallization damage, most prevalent in the Ohio Sandstone (Fig. 16), also occurs in the Nepean Sandstone. Water that has penetrated the walls migrates to the surface *via* porous zones within the stone or mortar. As the mortar is hard, Portland-type cement, moisture migration within it is impeded and thus moisture moves preferentially in the typically porous Ohio Sandstone and to a lesser extent in the Nepean Sandstone. With the evaporation of the water, salt crystals are formed in the near-surface pores of the stone, generating tremendous pressures that causing fracturing, which results in surface erosion and exfoliation. In order to effect lasting repair work, a thorough understanding of the physical properties, especially water absorption and vapour transmission of each of the stone types and bonding materials, is required.

The salts that damage the sandstones are in part derived from the reaction of acid rain with calcium carbonate (present mainly in the mortars). The acid rain itself (formed when sulphur dioxide in the atmosphere combines with moisture to form weak sulphuric acid) has little direct effect on the high silica sandstones. However, it reacts with calcium carbonate to form calcium sulphate (gypsum). Crystallization of calcium sulphate and similar salts damage the stone from within.

In the 1970s, a wash of dense Portland cement was applied to stabilize the surface of some of the exterior building stones. It proved to be ineffective and, in fact, has been detrimental. The wash acted in a similar manner to soiling, trapping moisture and causing erosion and cavernous decay of the stone that it was intended to protect. From 5 mm to 30 mm of the surface of some stone was lost in less than 20 years! (PWGSC, 1994).

Figure 14 Canada's completed reconstructed Centre Block, *circa* 1953. Photo taken from the West Block. National Archives of Canada, C5856.

Remediation

Since the evaluation of the condition of the stone work in 1994, much remedial work has been undertaken. Remediation focussed on three critical elements: conservation and long-term durability of the stone; **repointing** of the masonry; and dismantling, rebuilding and/or reinforcement of structurally unstable elements. PWGSC and their consultants undertook additional research in order to ensure the long-term viability, not only of the stone, but also of the entire masonry assembly.

The following is a summary of the remedial measures than have been undertaken (PWGSC, 1994):

Stone

- Cleaning of all Ohio Sandstone projecting courses using various techniques
- Cleaning of about 20% of the Nepean Sandstone.
- Applying poultices to affected areas of Ohio Sandstone to draw out salts from the pores
- Chemical consolidation of stone in isolated locations
- **Dutchman** repairs

- Crack repairs and joint pinning
- Removal of cement **parging**
- Replacement of a portion of the Ohio Sandstone in **turrets**, chimneys and buttresses
- Replacement of a portion of the Indiana Limestone, that was used inappropriately as a replacement stone, with Nepean Sandstone

Mortar

- **Raking**, to a 5 cm depth, all mortar on the ground floor, in the **piers** and towers, in projecting elements, in the upper band of Ohio Sandstone and in 40% of the Nepean Sandstone in the walls
- **Repointing** with mortars formulated for specific conditions

Structural

- Dismantling, rebuilding and reinforcement, where necessary, of the towers chimneys, **pilasters** and **parapets**

The direct cost of the repair and masonry conservation work was estimated in 1994 at $2.2 M, excluding costs for scaffolding, temporary works, and management and consultants fees. This estimate was included as part of a $16 M rehabilitation estimate that also included rehabilitation of the foundations, roofing, windows, doors, and mechanical and electrical systems. Final costs were $18.8 M when completed in 1998 (PWGSC, *see* www.pwgcs.gc.ca).

Similar remedial work undertaken on the Peace Tower was completed in 1997 at a cost of $9.9 M. Remedial work, currently underway on the Library, is estimated at $5.6 M (PWGSC, *see* www.pwgcs.gc.ca).

RECENT ACTIVITIES AND CONSTRUCTION

The Parliament Hill promontory is underlain by the Cobourg beds (Unit F) of the Ottawa Formation (Williams *et al.*, 1984) comprising thinly to massively bedded limestone with thin calcareous shale and calcareous sandstone interbeds. Beds in general dip very gently, 5°, in a direction of 016° azimuth; two prominent, near vertical joint sets are oriented at approximately 046° and 130° (Golder and Associates, 1980).

In 1982, initiated by anomalous slope inclinometer readings obtained by

Figure 15 Deterioration of mortar due to freeze/thaw cycling. Note the adjacent Nepean Sandstone, heavily soiled in part, has also suffered. Cracked mortar and stone facilitated further entry of moisture. PWGSC, 1995.

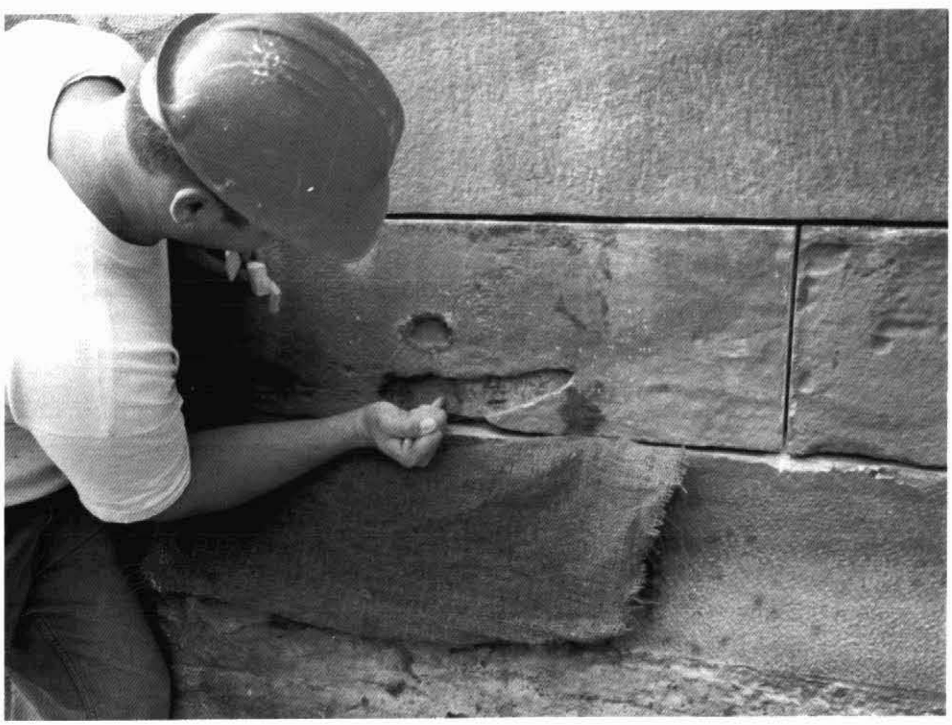

Figure 16 Exfoliation and crumbling of sandstone due to salt crystallization is one of the principal mechanisms contributing to the deterioration of Ohio and Wallace Sandstones. PWGSC, 1995.

Golder Associates, investigations were undertaken to determine if there was any possibility of deep-seated slope movement that might affect the Centre Block and the Library. Slope monitoring was carried out by the National Research Council (Bozozuk and Law, 1985) and an engineering geology appraisal was undertaken by the Geological Survey of Canada (Evans, 1986). Evans' report stated that the conditions necessary for slumping, lateral spreading, or transitional sliding do not exist in the slopes of the Parliament promontory.

The most recent construction to the Centre Block was the addition of space to accommodate new electrical, mechanical, and communications equipment and to provide storage space and delivery reception facilities. In order to preserve the historic facade of the buildings and to retain the visual character of Parliament Hill, it was decided that the excavation of an underground complex, that on completion would be entirely hidden, would be the best solution.

A 2-storey underground space approximately 50 x 40 m, called the Centre Block Underground Services (CBUS), was excavated on the north side of the Centre Block (Fig. 17). An innovative system of monitored and controlled blasting was carried out. This was done without disruption to existing heritage structures and monuments or the natural grade of the hill, nor was there disturbance to the adjacent limestone cliffs. The excavation of approximately 30,000 m^3 of rock was undertaken between July and September 1997 at a cost of $2.5 M (*Geotechnical News,* 1999).

ENDNOTE

For those who wish to delve further into the history of the construction of the Federal Parliament Buildings and related aspects, there are a number of excellent photo essays (Lund and Malak, 1967; Milton, 1974; and Malak, 1999), historical accounts (Varkaris and Finsten, 1988; Bourrie, 1996; Young, 1995), geological guides (Baird, 1968; DeGrace, 1982), and technical descriptions (Comarty, 1924). Information on recent and planned restoration works, walking tours, and related information can be found at the web sites www.pwgcs.gc.ca and www.parliament gc.ca. In addition, the National Archives photo collection contains a myriad of high-quality, large-format images of construction activities on Parliament Hill, both for the original buildings and for the reconstruction of the Centre Block and the Peace Tower.

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A series of popular papers on the building stones of the legislative buildings in Canada is the idea of Doug VanDine, editor for this new series. Critical readers for this paper were Ed Freeman and Doug VanDine, and their comments, along with those of Roger Macqueen, have considerably improved the paper and are much appreciated. Dave Sargent of GSC Calgary helped with completion of the digital figures.

Figure 17 Excavation for the Centre Block Underground Services space (CBUS) involved the removal of about 30,000 m^3 of rock during a 3-month period in 1997. PWGSC 1997.

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