

ENGINEERING GEOLOGY OF AGGREGATES BRITISH COLUMBIA

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ABSTRACT

Aggregates represent an often overlooked, but important portion of the mining industry in British Columbia. Engineering characteristics of aggregates are directly dependent on the geological composition and mode of origin of the sediments or rock being mined. A brief historical overview is provided for context, and then methods used for the engineering quality assessment of aggregates in British Columbia are presented, with examples of typical test data. Finally, a summary of problems and projected trends associated with engineering geology and quality in the British Columbia aggregate industry is provided.

INTRODUCTION

Historical Background

Historically, British Columbia has enjoyed a plentiful supply of economic, good quality aggregate, due to its geologic heritage and physiography. The combination of mountainous terrain composed of highly varied bedrock geology, and Pleistocene and Recent glaciofluvial activity produced numerous deposits of sand and gravel. Many deposits were located within or near the areas in which aggregates were required.

In fact, sand and gravel for use in construction was so plentiful, easy to find and develop, that little thought was given to quality testing, demand forecasting or inventory development, as has been done in areas where aggregates are less plentiful. Fortunately, many of the deposits produced materials of high quality.

British Columbia's heavily-populated south coast region consumes at least half the total aggregate produced in the province. Areas which are now heavily populated and extensively developed were once dotted with aggregate pits and a few quarries. Later, growth in the Greater Vancouver region population led to mining of larger deposits in areas such as south Surrey, Langley, Mary Hill (Port Coquitlam) and Coquitlam River valley in Coquitlam. These deposits differed from the smaller, local pits which provided the earlier supplies of aggregate in that they represented thicker, more extensive deposits where the economy of scale can be exploited.

Quality Testing of Aggregates

As the demand for aggregate increased, consideration of the quality requirements became more important. The combined effects of rapid population growth, environmental awareness, the stream-proximal

location of most aggregate deposits, and depletion of older pits resulted in steadily-mounting pressure upon the aggregate industry. As well, owners and engineers are demanding higher quality for all materials they use, including aggregates. Troublesome and expensive problems can sometimes be attributed to certain components of aggregates, so owners and specifiers have adjusted their specifications to ensure that only tested and proven materials are used on their projects.

Unlike other regions, where aggregate quality testing protocols can be at a considerably higher level, those in British Columbia are generally less stringent. This can be attributed in part to the overall natural high quality of many British Columbia aggregate sources, many of which have had a history of successful performance.

For road construction and asphalt paving, *Superpave* and other recently-developed standards have raised quality requirements relative to those previously used. Factors such as increased crush counts, and the use of angular rather than naturally-abraded (rounded) aggregates, have resulted in either the need to use crushed oversize aggregate or to blend in crushed quarried stone to meet the necessary quality standards. British Columbia roadways, with their constant heavy wheel loads, high traffic volumes, and low rehabilitation budget allowances, are at risk. Applying the new standards can avoid problems like deeply rutted wheel paths, heavy alligator cracking and premature pavement deterioration.

Ramping up of quality requirements in Standards such as CSA and *Superpave*, modified practice for new construction projects, and the need to meet requirements set for foreign markets where British Columbia aggregates are now being shipped is forcing aggregate producers to undertake higher aggregate testing protocols.

In contrast with eastern and central Canada, where quality control costs are estimated to be as much as

\$0.65/tonne of the cost of certain aggregate products, those in British Columbia are generally far lower. Typical costs for quality control testing in British Columbia range from \$0.0/tonne to \$0.10/tonne.

TEST STANDARDS

The test standards used in British Columbia generally were developed in eastern and central Canada, for example Canadian Standard Association (CSA), or in the United States, for example American Society for Testing and Materials (ASTM) and American Association of State Highway and Transportation Officials (AASHTO). Their adoption, use and enforcement in British Columbia have been uneven, often lagging behind that in other regions. Occasionally, the use of British Standards, such as BS 812, is seen, reflecting the authority accorded those test standards.

Some test methods that are widely used and accepted in other regions of Canada are not as well known or as commonly used in western Canada. An example of this would be the Micro-Deval test (CSA A23.2-23A, -29A), which has been widely accepted and applied in Ontario, but only used in a few laboratories in British Columbia, including two Ministry of Highways facilities. Results from this test are promising, and it may be included in the next revision of the British Columbia Highways Standards.

The British Columbia *Master Municipal Specification* document generally references test methods from CSA, ASTM, and British Columbia Highways.

Canadian Standards Association (CSA)

Many of the test methods provided in CSA A23.1/A23.2, "Concrete Materials and Methods of Concrete Construction/Methods of Test for Concrete", assess quality of *concrete* aggregates. In practice though, these test methods are also used in British Columbia to assess aggregate used in other applications, including road base aggregate, paving aggregate, railroad ballast, and shoreline and coastal works materials.

Most of the CSA tests have equivalents in other standards. Typical CSA tests used in British Columbia include Sieve Analysis, Organic Impurities, Sulphate Soundness, Los Angeles Abrasion, Concrete Prism, Relative Density (i.e., "Specific Gravity") & Absorption, Flat & Elongated Particles, and Accelerated Mortar Bar tests.

In addition to these tests, CSA A23.2-00 also provides two Standard Practices that provide analytical tools for assessing the degree to which new concrete

construction may be affected by Alkali-Aggregate Reaction in concrete.

British Columbia Ministry of Transportation (BCMOT)

The Provincial Ministry of Transportation has developed test standards that are given in Standard Specifications for Highway Construction. Some of the test methods given in this standard have been adopted and modified from other existing test standards to reflect experience with British Columbia aggregates. Test methods specified in the British Columbia Standard Specifications are taken from BCH test procedures standards, and from CSA A23.2.

Aggregates to be used for highways construction are required to meet applicable BCH specifications.

American Society for Testing and Materials (ASTM)

The Testing Standards given in ASTM documents are voluminous and wide-ranging. Tests which evaluate aggregates are found in "Concrete and Aggregates", as well as in "Soil and Rock" volumes, and involve dozens of individual test methods. Some of the more commonly-used tests include Bulk Density, Sulfate Soundness (Sodium or Magnesium Sulfate), Specific Gravity & Absorption, Los Angeles Abrasion, Sieve Analysis, Petrographic Examination of Aggregate, Accelerated Mortar Bar Test, Concrete Prism Test, and Durability Index.

American Association of State Highway and Transportation Officials (AASHTO)

This intergovernmental body, of which the British Columbia Ministry of Transportation & Highways is an associate member, has developed a number of test procedures and specifications that are based upon similar requirements for road and highway construction. The focus of these tests is to evaluate and qualify aggregates specifically for road transportation. Hence, the emphasis is on tests of characteristics of aggregates that affect durability of pavements (asphalt and concrete), bridge decks and other bridge components, road bases, and road surfacing.

AASHTO thus provides tests that parallel those given in CSA or ASTM, but also provides a number of tests which are unique. In British Columbia, the Ministry of Transportation standards apply versions of some AASHTO tests.

California Department of Transportation (CalTrans)

CalTrans also has developed a number of its own tests, and some variants differ from those in similar ASTM or CSA standards. Their tests include Sand Equivalent, Los Angeles Rattler, Cleanness Value, and others.

The California market is a current as well as potential market for British Columbia aggregate suppliers located at or near the ocean; so many aggregate suppliers have elected to test their products using CalTrans test standards.

GEOLOGY OF AGGREGATES IN BRITISH COLUMBIA

In British Columbia, the proportion of aggregate derived from natural sands and gravels far exceeds that produced from crushing quarried rock. Research by Levelton (1996) found that only 14% of aggregate supplied to the Lower Mainland region of the province was derived from quarried materials. Although the proportion may be slightly higher now for the South Coast, on a provincial basis, the proportion is lower.

The surficial deposits which comprise most of the aggregate supplies in British Columbia are of fluvial or glaciofluvial origin. Many are Pleistocene or Recent in age, and the geological composition of most reflects the regional geology of the area where the deposit is located, although particles that have been transported from sources a great distance away from the deposit are common. Some typical far-traveled components include sandstones and quartzites in lower Fraser Valley deposits whose sources are formations in the Rocky Mountains. Indicated travel distance for these clasts would be on the order of 1500 to 2000 kilometres.

By contrast, some sand and gravel operations have been established in deposits which are of local provenance, for example, alluvial or colluvial deposits. In these cases, transport of sediments may have been only a few hundred meters. These deposits tend to be uniform in composition, and poorly-sorted, with angular particle shapes. Although some are suitable material for aggregates, others are of poor quality.

The most desirable aggregate resources tend to be in deposits that are of fluvial or glaciofluvial nature. Sediments in these deposits generally have favourable physical qualities, due in part, to “natural processing” by fluvial and/or glacial transport. Transport by glacial ice and/or stream water erodes weaker material, removes unwanted silt and clay fines, and sorts the material hydraulically to produce sand and gravel deposits of good to excellent quality aggregate.

Deposits with more complex settings, such as those consisting of materials from drainages with varied bedrock geology and glacially transported material are mixed, have highly varied clast compositions.

Partly due to local bedrock geology, some regions lack construction-quality aggregate resources. For example, sand and gravel deposits in some portions of the Rocky Mountains contain high proportions of weak or otherwise undesirable rocks, such as mudstone, claystone, ironstone, siltstone, shale, coal, or poorly indurated sandstone. Where transport distances have been short, these weaker materials survive and can be major components of the deposited aggregate material. This can result in aggregate of marginal quality, and in some cases, precludes the use of certain pits for aggregate uses where premium quality is required. Use of these types of aggregates can affect the durability and service life of constructed works made with them; road bases may deteriorate, and asphalt pavements may undergo stripping, rutting and popouts, and development of alligator cracking and potholes.

For some Rocky Mountain communities and regions, the identification and development of aggregate sources of acceptable engineering quality is an ongoing challenge. With the continuing drive for increasing quality in infrastructure construction, and the ‘spotty’ nature of sand and gravel deposits in mountain regions, exploration for and testing of these resources is hard-pressed to keep pace. In some areas, development of quarried rock aggregate sources may provide a reasonable alternative to traditional sand and gravel aggregate resources. This is particularly true for regions where annual flooding occurs. In these areas, the need to provide large-size armourstone and rip-rap material to protect against flooding has escalated in recent years. Quarried rock sources will likely become more common for rip-rap as well as aggregate production here.

ENGINEERING QUALITY OF AGGREGATES

Overall, natural sand and gravel aggregates in the western part of the province are of higher quality than those in the east and northeast parts. This resulted from a combination of regional geology, glacial history, and physiography.

Igneous and metamorphic crystalline rocks that underlie central and western British Columbia tend to be of high strength and durability (Table 1). A notable exception is the low quality of aggregates found in the Prince Rupert region, where local bedrock consists of metamorphic rocks of low strength, like phyllites, schists, and gneisses. As a result, Prince Rupert imports aggregate materials periodically to meet requirements for certain engineering projects.

Eastern and northeastern British Columbia is underlain mainly by sedimentary rocks, including formations of weaker, fine-grained sediments, claystone, mudstone, poorly-indurated sandstone, and coal. Where transport distances have been short, these weak components persist and may be important components of aggregate deposits in these areas. In contrast, where transport distances of materials which comprise many sand and gravel deposits are greater, weak components break down and are removed so the resulting aggregates are of better quality.

TEST METHODS – GENERAL TRENDS

The following engineering tests, when run singly or in combination, have been found to be very effective indicators of overall physical quality of British Columbia aggregates. Among these tests are:

Petrographic Examination – used to identify weak geologic components and highlight specific rock types known to be linked with poor performance, both in the field and in laboratory testing. This test procedure is an excellent tool for quickly assessing the quality of either a production aggregate or of a proposed (unprocessed), “pit-run” source of material, in coarse or fine fractions. It can help to set direction for subsequent phases of investigation of new sources by highlighting problem components which will require further attention, either by additional testing, or through specialized processing to remove unwanted components. In addition, the Petrographic Examination can be used to detect changes in production aggregates that may require fine-tuning of the processing methods or to indicate that quality has changed.

Petrographic Number (PN) – the PN is a numeric index of a coarse aggregate’s overall physical-mechanical quality and is based on a method developed in Ontario in the 1950s. It uses information generated in the Petrographic Examination, but focuses on the classification of the aggregate sample on the basis of its relative quality groupings. Typical quality classifications are “Good”, “Fair”, “Poor” and “Deleterious”. When the sample has been classified, the relative percentages of each quality class are multiplied by a “Petrographic Quality Factor”. In common usage, factors used are “1” for Good, “3” for Fair, “6” for Poor and “10” for Deleterious. Higher PN numbers indicate lower aggregate quality. Typical ranges for the PN number are: 100 to 140 for “Good”, 140 to 160 for “Fair”, 160 to 200 for “Poor”, and more than 200 for “Unsuitable”.

While this method can be used as a Quality Control test for production aggregates, its application also extends to evaluation of new aggregate sources, and

assessment of specific aggregate problems by comparison of “before” and “after” conditions.

Specific Gravity (“Relative Density”) & Absorption – provides a measure of the porosity of the material, and its heft. These characteristics can be correlated with other performance criteria, to evaluate the material’s ability to absorb moisture, resist deterioration under freezing and thawing conditions, and so on. Intergranular porosity if high often indicates poor quality aggregate.

Magnesium Sulphate Soundness – like the absorption value, $MgSO_4$ loss % can identify materials with a tendency to breakdown under repeated cycles of wetting and drying and/or freezing and thawing.

Micro-Deval Abrasion – this index has been found to be a good predictor of the overall competence of the material, as well as its resistance to breakdown under abrasive and other stress-inducing conditions.

In field performance, aggregate breakdown caused by various mechanisms can range from negligible to serious. Factors that influence resistance are the rock type, the exposure conditions, and the specific forces acting on the aggregate. The most frequently observed causes of aggregate deterioration and failure in British Columbia are the effects of running water, wave action, abrasion, loading stresses, freezing and thawing, and chemical attack. Selecting tests to accurately predict aggregate susceptibility to these forces can be a daunting task.

NEW APPLICATIONS OF EXISTING TESTS

Occasionally, these above described tests are used to assess the quality of materials for which they were not initially designed. For example, some rip-rap and armourstone specifications call for the use of concrete aggregate tests, such as Sulphate Soundness (CSA A23.2-9A, ASTM C-88). While this test provides an index of physical quality of the material under test, there is some confusion about the correct interpretation of the test data obtained from the small-size aggregate tests. Losses on larger pieces of stone (such as rip-rap) tend to be far lower due to the effects of lower surface area-to-mass ratios for the larger samples.

Another example is the Los Angeles Abrasion test, which is frequently specified in the quality testing regime for rip-rap. In preparing large samples for testing in the Los Angeles Abrasion machine, large pieces several inches across need to be manually reduced to appropriate gradings (typically 2” minus). This often involves breaking with a sledge hammer, and then reduction in a small laboratory jaw crusher. This latter method often produces highly angular, “flaky” pieces, which perform, poorly in the Los Angeles test.

TABLE 1: TEST DATA FOR SELECTED BRITISH COLUMBIA SAND & GRAVEL AGGREGATES

PARAMETER	AGGREGATE SOURCE					
	Vancouver Island	Sechelt Peninsula	Coquitlam Valley	Fraser Valley	Kamloops	Southeast B.C.
SG	2.88	2.656	2.72	2.75	2.73	2.64
Absorption	0.72	0.85	0.71	0.74	0.56	1.24
Petrographic Number	107 - 120	108 - 121	104 - 119	106 - 125	112 - 128	118 - 155
Petrographic Composition	Mafic volcanics, some sandstone & granitic.	Granitic, volcanic, minor metamorphic	Granite-diorite, volcanic, minor metamorphic	Mafic-felsic volcanics, quartzite, chert, metamorphic, sandstone.	Mafic- intermed. volcanics, quartzite, chert, granitic	Sandstone, quartzite, siltstone, limestone, shale
MgSO ₄ loss %	Sand: 2.9 Stone: 0.74	Sand:4.7 Stone: 0.87	Sand: 2.97 Stone: 0.56	Sand: 4.8 Stone: 0.4-1.4	Sand: 7 - 16 Stone: 0.6 - 5	Sand: 12 - 17 Stone: 5.8 - 8.5
Micro-Deval loss %	7	6.3	4.5	4.6	5.0 - 12.0	8.0 – 15.0
AAR Expansion %	AMBT: 0.07 - 0.32 CPT: 0.01 - 0.013	AMBT: 0.06 - 0.23 CPT: 0 - 0.02	AMBT: 0.32 CPT: 0.011 - 0.04%	AMBT: 0.19 - 0.52 CPT: 0.01 - 0.15	AMBT: 0.20 - 0.40 CPT: 0.013	AMBT: 0.10 - 0.36 CPT: 0.06
LA Abrasion Loss %	18.7	24.3	14 - 22	23.5	7 - 12	19 - 26

KEY: AMBT: Accelerated Mortar Bar Test (CSA A23.2-25A or ASTM C-1260) percent expansion at 14 days.

CPT: Concrete Prism Test (CSA A23.2-14A or ASTM C-1293) percent expansion at 1 year.

Losses near or in excess of 35% are not uncommon, when such preparation is used. Some specifications for construction materials set the Los Angeles loss limits at 35%, while some specifiers limit the loss to a maximum of 20%.

TEST METHODS – TYPICAL RESULTS

As noted earlier, high quality aggregate materials are more common in central and western British Columbia, while the quality of aggregates in the east is generally lower. Table 1 provides an overview of typical test data for aggregates from a variety of locations within British Columbia.

QUARRIED AGGREGATE

As noted earlier, there are comparatively few aggregate quarries in British Columbia. Historically, a few quarries in Vancouver and Victoria were operated to produce aggregate. Most notably, these included the basalt quarry in the present-day Queen Elizabeth Park in central Vancouver, as well as the present site of Butchart

Gardens in Victoria, where limestone was quarried for the production of Portland cement.

Today, British Columbia quarries that produce aggregate include Blubber Bay quarry on Texada Island; Texada Quarrying also on Texada Island; Producer’s Pitt near Victoria; Pitt River Quarries in Pitt Meadows; Mainland Sand & Gravel’s Cox Station quarry near Abbotsford; and Sumas Quarry near Abbotsford.

Current aggregate production from British Columbia quarries is estimated to be 5 million tonnes per year. However, recent efforts to market and distribute not only sand and gravel but also quarried aggregates to Washington, Oregon and California (ENR, Dec. 14, 2000) may push future production levels well beyond those of today.

Test data for some quarried aggregates are given in Table 2.

Some sand and gravel pits have bedrock cropping out within their property boundaries. This provides an opportunity for the blending of crushed high-quality bedrock with natural sand and gravel. One potential benefit is that blended production could extend the production life of the property.

CHALLENGES IN ENGINEERING QUALITY FOR BRITISH COLUMBIA AGGREGATES

British Columbia aggregate producers face a number of aggregate engineering quality problems. Among them are:

1. **Regional Poor Quality** – Aggregates of low quality occur in certain regions, as a result of local bedrock conditions and regional surficial geology. These include the Prince Rupert (north coast) area, where metamorphic schists and gneisses contribute gravel of low durability, and poor strength; and northeastern and southeastern British Columbia, where softer and weaker sedimentary rocks that occur in local gravels can downgrade the quality to a significant extent. As a result, exploration for high-quality gravel for use as construction aggregate during the development of coal resource areas at Elkford, Sparwood in the southeast, and Tumbler Ridge in the northeast was challenging.

2. **High Fines** - If there is a significant amount of silt and clay-sized material in the natural deposits it can add tremendously to the operating costs of a pit. Costs are incurred because of the need to wash and classify the sand, and to handle and eventually dispose of the fines. Impacts on mining parameters and environmental considerations help to further increase costs of mining.

This type of problem is illustrated in the aggregate pits of the Coquitlam Valley, east of Vancouver, where glaciofluvial deposits adjacent the Coquitlam River have been mined for many years. Estimates indicate that there are gravel reserves to support mining for forty more years, and the quality of the aggregates tends to be ‘good

to excellent’. The glaciofluvial sediments being mined are interlayered silty sands and silts with abundant gravels and sands and gravels. Thicknesses of the deposits range up to 100 metres or more. However, washing to remove silt is necessary to produce high quality aggregates to meet the required specifications. Subsequently, this places pressure on the producers to manage and dispose of the silt.

3. **Rounded and Smooth Aggregate** – Although it is not generally a problem, a high proportion of rounded aggregate particles with smooth surfaces can lead to lower-than-expected strengths for cementitious or asphaltic mixtures. The cementing agent cannot form strong bonds with very smooth aggregate particles. Aggregates with particles which have been water-transported for long distances are most susceptible to this problem. The typical solution has been to blend in crushed oversize aggregate or crushed rock to increase the proportion of particles with rougher surfaces.

4. **Reactivity in Concrete** – Many aggregates in British Columbia have some potential for “Alkali-Aggregate Reaction” (AAR) in concrete. AAR is a chemical reaction within hardened concrete, which causes it to expand over time. The reaction can continue indefinitely if sufficient alkalis are available to sustain the reaction. The hydroxyl ions of the concrete pore solution, which is highly basic, react with the alkaline and other unstable mineral phases in the concrete coarse and fine aggregate. Resulting expansion causes cracking in the cement paste and aggregates which adversely affects the strength and durability of the material. In severe cases, AAR leads to early weakening or disintegration of concrete, requiring either replacement or costly repairs.

TABLE 2: TEST DATA FOR SELECTED BRITISH COLUMBIA QUARRIED AGGREGATES

PARAMETER	QUARRY LOCATION				
	Vanc. Island 1	Strait of Georgia 2	South Coast 1	South Coast 2	Southeast 1
SG	2.96	2.715	2.72	2.74	2.677
Absorption %	0.46	0.22	0.51	0.43	0.89
Petrographic Number	103	109 - 144	104	108	108
Petrographic Composition	Basalt	Limestone	Granodiorite	Volcanic	Sandstone
MgSO ₄ loss %	0.5 - 1.8	0.6 - 5.5	0.5 - 2.8	1.8	1.16
Durability Index	--	72	85	--	--
AAR Expansion %	AMBT: 0.05	CPT: 0.006	AMBT: 0.09	AMBT: 0.09 CPT: 0.01	AMBT: 0.19 CPT: 0.06
LA Abrasion Loss %	7.5	22.4	25.0	13.7	26.1

Fortunately, this phenomenon is not as common in British Columbia (Shrimer, 2000) as in other regions of Canada and the United States because of the use of generally low alkali cement. Despite this, there are at least a hundred sites in British Columbia where concrete has been affected by AAR. Examples include Alexandra Bridge, at Boston Bar; Brockton Point, Stanley Park, Vancouver; Daisy Lake Dam, Squamish; Massey Tunnel walls, Richmond-Delta; and the Marine Way-Capilano River Bridge, Northwest Vancouver.

While this phenomenon is not as serious as that reported in other provinces, owners and technical professionals should be aware of and test to avoid using aggregates that have potential for AAR. Methods given in CSA, particularly A23.2-27A, can be used to evaluate whether AAR potential in aggregates might produce a deleterious reaction in concrete, and can also serve as a basis for avoiding or determining appropriate preventive measures to use with an aggregate where AAR is a high risk.

Currently, test data indicates that approximately 80% of British Columbia aggregates exceed the CSA limits for expansion in the Accelerated Mortar Bar test, while roughly 40% of the aggregates tested in the Concrete Prism Test exceed the CSA limit.

5. **Quality Testing Protocol** –testing of aggregate in British Columbia has not generally been carried out to the levels seen in other regions of Canada or the United States. In the future, in-province and exterior markets will demand testing to demonstrate that aggregates supplied meet specification requirements for the specific market, and for the intended applications. Aggregate producers will need to factor in higher costs for quality control to meet these demands and maintain their markets.

CSA A23.1 stipulates that testing of concrete aggregates should be done annually “as a minimum”.

The British Columbia Ministry of Transportation & Highways generally requires that testing results be furnished in advance of specific projects. In contrast, the Department of Transportation in neighbouring

Washington State requires suppliers of aggregates and/or concrete to submit their aggregates for testing in order to qualify for inclusion on the “Aggregate Sources Approval” list. Once an aggregate supplier is on Washington’s list of approved sources, the qualification is good for up to five years.

CONCLUSION

Aggregates in British Columbia have been developed close to their markets, and British Columbia has enjoyed the benefits of inexpensive, plentiful and generally high-quality aggregate supplies. The natural occurrence of high quality aggregate in the province has been fortuitous, and resulted in low emphasis on engineering quality testing. However, changing markets; rapid depletion of aggregate resources; increased economic and environmental pressures; and increased awareness of potential engineering and liability problems stemming from the use of under-tested aggregates must be considered. Today, to maintain existing and attract new markets, rigorous testing to demonstrate the engineering quality of aggregates is necessary and will become normal practice in British Columbia.

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