

FINAL REPORT
SURVEY OF VIRGINIA AGGREGATES FOR CHLORIDE CONTENTS

by

Gerardo G. Clemeña
Research Scientist

and

John W. Reynolds
Chemist

(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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ABSTRACT

A major cause of concrete bridge deck deterioration is the corrosion of the reinforcing steel which, in turn, is caused by the presence of extremely high concentrations of chloride ions in the concrete. It was believed that the chloride came almost entirely from applications of deicing salts and that the contribution from the concrete mix was insignificant by comparison with the corrosion threshold value. A recent accidental finding of significant amounts of chloride in some concrete aggregates in Virginia, and reports of similar occurrences in other states, prompted a survey to determine the chloride contents of Virginia aggregates being used in concrete for highway construction and maintenance.

Aggregates from 104 sources were analyzed for their total chloride and water-soluble chloride contents. The results were examined in the perspective of the current state of knowledge on the corrosion process.

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INTRODUCTION

A major expense in maintenance is the repair of deterioration of concrete bridge decks caused by the corrosion of the reinforcing steel resulting from the intrusion of chloride ions from deicing salts. In the formulation of decisions regarding bridge deck maintenance, it has been suggested that when the total chloride content in the concrete is greater than 2.0 lb. Cl⁻/yd.³ (1.2 kg/m³), or 510 ppm Cl⁻ by weight in a typical bridge deck concrete having a cement content of 658 lb/yd³ (390 kg/m³), the concrete should be removed to a level below the top mat of rebars or the entire deck should be replaced,⁽¹⁾ if an effective, permanent repair is desired. (The corrosion threshold of 510 ppm total chloride is based on an assumed 50% water solubility.) The rationale is that steel in concrete contaminated with that amount of chloride, if not already exhibiting symptoms of active corrosion, will eventually corrode once the necessary factors of moisture and oxygen are present in sufficient amount in the concrete.

Since almost anything contains at least a slight amount of chloride, the total chloride content in bridge deck concrete consists of contributions from the various ingredients of concrete, i.e., the cement, mix water, admixture and aggregate, in addition to that from deicing salts. It is believed that the normal contributions from the cement, mix water, and admixture are negligible since their total is estimated to be less than 80 ppm Cl⁻ by weight of concrete.⁽²⁾ The amount of chloride contributed by aggregates had also been considered insignificant until recently, when some aggregates in the Commonwealth of Virginia were found to have chloride contents as high as 280 ppm.⁽³⁾ (Chloride-bearing aggregates had concurrently been found in Florida,

*Presently with Perkin-Elmer Corporation, Houston, Texas.

Ohio, Utah, and Quebec.) Since aggregate is a major constituent of concrete, even a small amount of chloride in the aggregate may prove significant in the total chloride content of the concrete. This finding of high chloride contents in some aggregates therefore disclosed a need to determine the chloride contents of other aggregates in the state.

In addition, it was thought necessary to determine what portion of the total chloride in an aggregate is available to contribute toward corrosion, if it does. And, availability can vary with aggregates, depending probably on (1) how permeable an aggregate is to water, (2) how accessible the chloride is for water leaching, and (3) how strongly the chloride is bonded to the other constituents in the aggregate.

This report presents the findings of a survey made to determine the chloride contents of the different aggregates in Virginia and what portion of that chloride contributes to the corrosion process.

SURVEY METHODOLOGY

Included in the survey were 104 quarries, 6 of which are located in the neighboring states of West Virginia, Kentucky, and North Carolina, and the remainder in Virginia. Aggregates produced in these quarries are being, or had been, used in concrete by the Virginia Department of Highways & Transportation. Figure 1 shows the locations of these quarries and the types of aggregates produced.

The survey consisted of sampling the quarries and analyzing the aggregate samples for acid-leachable and water-leachable chloride.

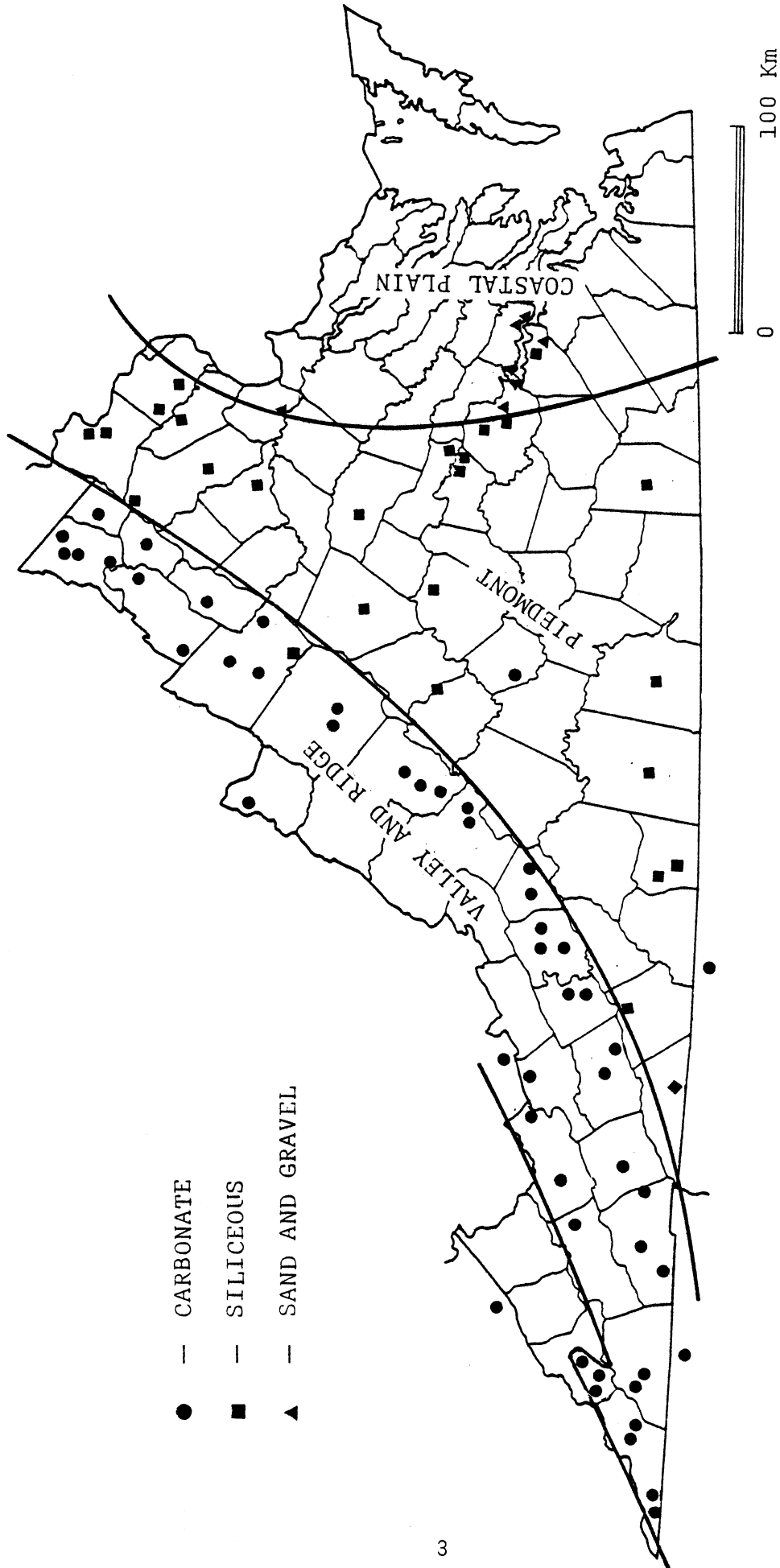


Figure 1. Physiographic provinces of Virginia and locations of quarries sampled.

Sampling Procedure

In sampling each quarry, the general rules given below were followed.

1. All visible stratifications that appeared to vary in color and structure were sampled.
2. A sample weighing more than 25 kilograms was taken from each stratum representing more than 10% of production.
3. Strata representing less than 10% of production were combined on the basis of structure and location and randomly sampled to yield samples weighing more than 25 kilograms.
4. Where the quarry consisted of many thin strata of varying character, the quarry face was sampled at a minimum of 10 selected locations.

These rules were derived by combining sampling practices reported elsewhere. (4,5)

Because of the recent tightening of safety regulations by a federal regulating agency, access to some quarries was impossible. In such cases, combined samples were taken from stockpiles.

Chloride Analysis Procedure

The total, or acid-soluble, chloride in each aggregate sample was determined by the procedure developed by Berman, (6) which involves digestion of the pulverized sample in dilute nitric acid and potentiometric titration of the filter extract with standard silver nitrate solution, using either a silver-ion or chloride-ion specific electrode as an indicator.

The water-soluble chloride was determined by a procedure, described and suggested by Clear and Harrigan (7) as a standard procedure to enable comparison of data from different studies, wherein a pulverized sample is boiled in distilled water for 5 minutes, let stand for 24 hours, and then the filter extract titrated with standard silver nitrate as described above.

In both analyses, the titration endpoint was determined by the application of a Gran plot as described by Clemeña, Reynolds, and McCormick. (8,9)

RESULTS AND DISCUSSION

The Commonwealth of Virginia, as shown in Figure 1, is divided into three major physiographic provinces: (1) the Valley and Ridge, (2) the Piedmont, and (3) the Coastal Plain.⁽¹⁰⁾ These physiographic provinces provide aggregate materials that vary from the highly metamorphosed rocks of Precambrian age to the unconsolidated sand and gravel deposits of Recent age. The Valley and Ridge province is made up of sedimentary rocks, mainly limestone and dolomite formations with some siliceous sandstone coming from the west slope of the Blue Ridge Mountains. In the Piedmont province, aggregates are produced mainly from igneous and metamorphic rocks, including granite and various types of gneiss, diabase, basalt, slate, and marble. The sedimentary formations in the Coastal Plain province produce sand and gravel, composed mainly of quartz.

Tables 1 through 3 present the determined total chloride contents of aggregates obtained from quarries in the various provinces. The tables indicate both a mean value for each quarry, or aggregate source, and the extent of variation from it, i.e., the low and the high values. It can be generally stated that the sedimentary rocks, mainly limestone and dolomite, of the Valley and Ridge province contain the highest levels of chloride, the igneous and metamorphic rocks of the Piedmont the next highest, and the sand and gravel of the Coastal Plain the least (Figure 2). The grand means for the three provinces, obtained by averaging total chloride levels for the quarries in each province, are 150 ppm, 60 ppm, and 20 ppm for the Valley and Ridge, the Piedmont, and the Coastal Plain, respectively (Table 4). The grand mean of 150 ppm for the Valley and Ridge province agrees with the 200 ppm Cl⁻ determined much earlier by H. N. Stokes as average in 345 limestones.⁽¹¹⁾

More important, the total chloride concentrations at 4,5-in. (11.4 cm) depths of concrete decks observed by H. Newlon⁽¹²⁾ for some Virginia bridges which have been in service for at least 15 years show good agreement with the chloride concentrations observed in this survey (Table 5) for the aggregates known to have been used in the construction of those bridges. This agreement indicates that it is fairly logical to attribute most of the chloride present at an appreciable depth of a concrete deck to the aggregates used.

TABLE 1

Chloride Contents of Aggregates from the Valley and Ridge Province

Aggregate Source	Description	Number of Samples	Chloride Content, ppm						Water-Soluble Chloride: Total Chloride
			Total			Water-Soluble			
			Low	High	Average	Low	High	Average	
VR-53	Limestone	6	20	150	70	10	90	50	0.7
VR-42	Limestone, dolomite and dolomitic limestone	5	60	360	170	20	130	90	0.5
VR-54	Dolomite and dolomitic limestone	3	130	340	250	80	150	100	0.4
VR-55	Limestone and dolomitic limestone	5	50	270	140	50	110	70	0.5
VR-56	Limestone	3	10	50	30	0	50	20	0.6
VR-40-1	Argillaceous limestone	3	30	50	40	30	50	40	1.0
VR-40-2	Limestone	4	40	170	90	30	150	70	0.8
VR-57	Dolomite, dolomitic limestone and limestone	4	90	180	140	50	90	70	0.5
VR-58	Limestone	2	40	90	60	30	40	40	0.6
VR-5	Limestone	1	90			70			0.8
VR-37	Dolomite	2	140	340	240	80	160	120	0.5
VR-35	Limestone	2	30	130	80	10	40	20	0.3
VR-34	Limestone, dolomitic limestone and dolomite	12	20	120	70	10	80	30	0.5
VR-33	Limestone and dolomite	7	40	100	70	20	70	50	0.8
VR-32	Dolomite and limestone	11	0	60	30	10	50	30	1.0
VR-59	Limestone	4	50	210	100	40	110	70	0.7
VR-60	Limestone	5	80	130	110	60	90	70	0.7
VR-61	Limestone	2	70	110	90	50	60	60	0.6
VR-62	Limestone	1	20			20			1.0
VR-63	Limestone and dolomitic limestone	3	60	130	100	40	80	60	0.6
VR-30	Limestone	3	40	90	60	30	50	40	0.6
VR-28-1	Banded dolomite	4	50	190	110	10	90	40	0.4
VR-28-2	Brecciated quartzite and sandstone	5	10	100	60	10	50	30	0.5
VR-50	Limestone	9	60	130	100	20	110	60	0.6
VR-64	Limestone	3	120	170	140	20	110	60	0.4
VR-65	Limestone	3	180	760	500	30	110	80	0.2
VR-24	Shady dolomite	5	140	280	190	10	100	50	0.3
VR-66	Limestone	3	80	170	120	40	70	50	0.4
VR-67	Limestone	3	130	160	140	30	90	70	0.5
VR-68	Dolomite	4	280	430	360	90	170	120	0.3
VR-69	Limestone	3	170	180	180	40	80	60	0.3
VR-70	Limestone	3	80	140	110	50	110	70	0.7
VR-71	Limestone	3	120	230	160	60	100	80	0.5
VR-72	Dolomitic limestone	3	80	140	110	50	110	70	0.7

Table 1 (Cont.)

Aggregate Source	Description	Number of Samples	Chloride Content, ppm						Water-Soluble Chloride: Total Chloride
			Total			Water-Soluble			
			Low	High	Average	Low	High	Average	
VR-23	Dolomite	2	390	400	400	130	140	130	0.3
VR-74	Limestone	3	110	340	220	70	110	90	0.4
VR-75	Limestone	3	260	320	290	80	90	90	0.3
VR-25	Dolomite and limestone	4	160	490	270	70	150	100	0.4
VR-7	Dolomite and banded limestone	3	60	140	100	20	100	70	0.7
VR-18	Brecciated and laminated limestone	3	300	360	320	90	130	110	0.3
VR-76	Limestone	4	240	380	300	60	130	130	0.3
VR-21	Limestone	3	110	190	140	30	90	60	0.4
VR-12	Limestone	3	80	100	90	40	60	50	0.6
VR-77	Limestone	3	110	170	140	40	80	60	0.4
VR-13	Limestone	3	100	130	120	30	50	40	0.3
VR-78	Limestone	3	160	360	270	50	80	70	0.3
VR-79	Dolomite	2	140	180	160	90	120	100	0.6
VR-15	Limestone	3	50	80	70	40	70	60	0.9
VR-10	Dolomite	3	210	330	280	70	120	100	0.4
VR-11	Limestone	3	70	90	80	20	40	30	0.4
VR-80	Limestone	3	320	340	330	90	100	90	0.3
VR-81	Limestone and dolomite	3	140	250	180	40	80	60	0.3
VR-82	Sandstone and quartzite	6	20	90	50	10	60	30	0.6

TABLE 2

Chloride Contents of Aggregates from the Piedmont Province

Aggregate Source	Description	Number of Samples	Chloride Content, ppm						Water-Soluble Chloride: Total Chloride
			Total			Water-Soluble			
			Low	High	Average	Low	High	Average	
P-2	Diabase	2	100	170	130	10	40	30	0.2
P-31	Diabase	2	70	90	80	10	20	20	0.3
P-32	Diabase	2	70	170	120	10	20	10	0.1
P-30	Diabase	2	60	70	60	0	20	10	0.2
P-29	Diabase	2	90	100	100	20	40	30	0.3
P-33	Diabase	3	40	170	130	20	40	30	0.2
P-34	Greenstone	1	60			70			1.0
P-35	Greenstone	2	40	50	50	10	40	20	0.4
P-28	Basalt	8	20	50	30	10	20	10	0.3
P-5	Siltstone	2	50	50	50	30	30	30	0.6
P-24	Greenstone	3	10	30	20	0	30	10	0.5
P-51	Granite gneiss	3	0	50	30	0	20	10	0.3
P-1	Granite gneiss	11	40	80	60	0	50	20	0.3
P-36	Granite gneiss	1	50			10			0.2
P-37	Granite gneiss	1	30			0			0
P-20	Gneiss	1	20			10			0.5
P-38	Granite gneiss	1	30			30			0.5
P-39	Granite gneiss	1	10			0			0
P-19	Granite gneiss	3	20	30	30	10	10	10	0.3
P-40	Granite	3	20	40	30	10	20	10	0.3
P-22	Granite	2	30	40	40	0	30	10	0.3
P-41	Granite	3	10	20	20	0	10	10	0.5
P-42	Granite	2	30	40	40	10	10	10	0.3
P-43	Granite gneiss	3	10	40	30	0	10	10	0.3
P-44	Granite	3	30	60	40	20	40	20	0.5
P-50	Granite gneiss	1	0			0			0.8
P-45	Granite gneiss	2	30	60	40	30	30	30	1.0
P-15	Granite	1	10			10			0.3
P-46	Aplite	7	30	110	60	10	30	20	0.3
P-3	Slate	7	10	90	40	0	30	10	0.3
P-13	Arch Marble	7	10	100	40	10	70	20	0.5
P-47	Arch Marble	9	10	30	20	0	20	10	0.5
P-48	Marble	6	70	240	150	20	30	20	0.1
P-54	Granite gneiss	7	20	40	20	0	40	20	0.5
P-55	Granite gneiss	7	10	30	20	0	30	20	1.0
P-49	Granite and hornblende gneisses	4	20	30	30	20	30	20	0.7
P-56	Quartzite	3	70	110	90	10	10	10	0.1
P-57	Granite	2	100	130	110	10	40	20	0.2

Table 2 (Cont.)

Aggregate Source	Description	Number of Samples	Chloride Content, ppm						Water-Soluble Chloride: Total Chloride
			Total			Water-Soluble			
			Low	High	Average	Low	High	Average	
P-58	Granite	2	30	60	50	20	50	30	0.6
P-10	Granite gneiss	2	210	270	240	10	30	20	0.1

TABLE 3
Chloride Contents of Aggregates from the Coastal Plain Province

Aggregate Source	Description	Number of Samples	Chloride Content, ppm						Water-Soluble Chloride: Total Chloride	
			Total			Water-Soluble				
			Low	High	Average	Low	High	Average		
C-1	Sand and gravel	2	10	30	20	10	10	10	10	0.5
C-2	Sand and gravel	1	20			10				0.5
C-3	Sand and gravel	2	10	20	20	10	20	20	20	1.0
C-4	Sand and gravel	1	10			20				0.5
C-5	Sand and gravel	2	40	40	40	30	40	30	30	0.8
C-6	Sand and gravel	1	20			0				0
C-7	Sand and gravel	1	20			20				1.0
C-8	Sand and gravel	1	20			20				1.0
C-9	Sand and gravel	2	10	20	20	10	10	10	10	0.5

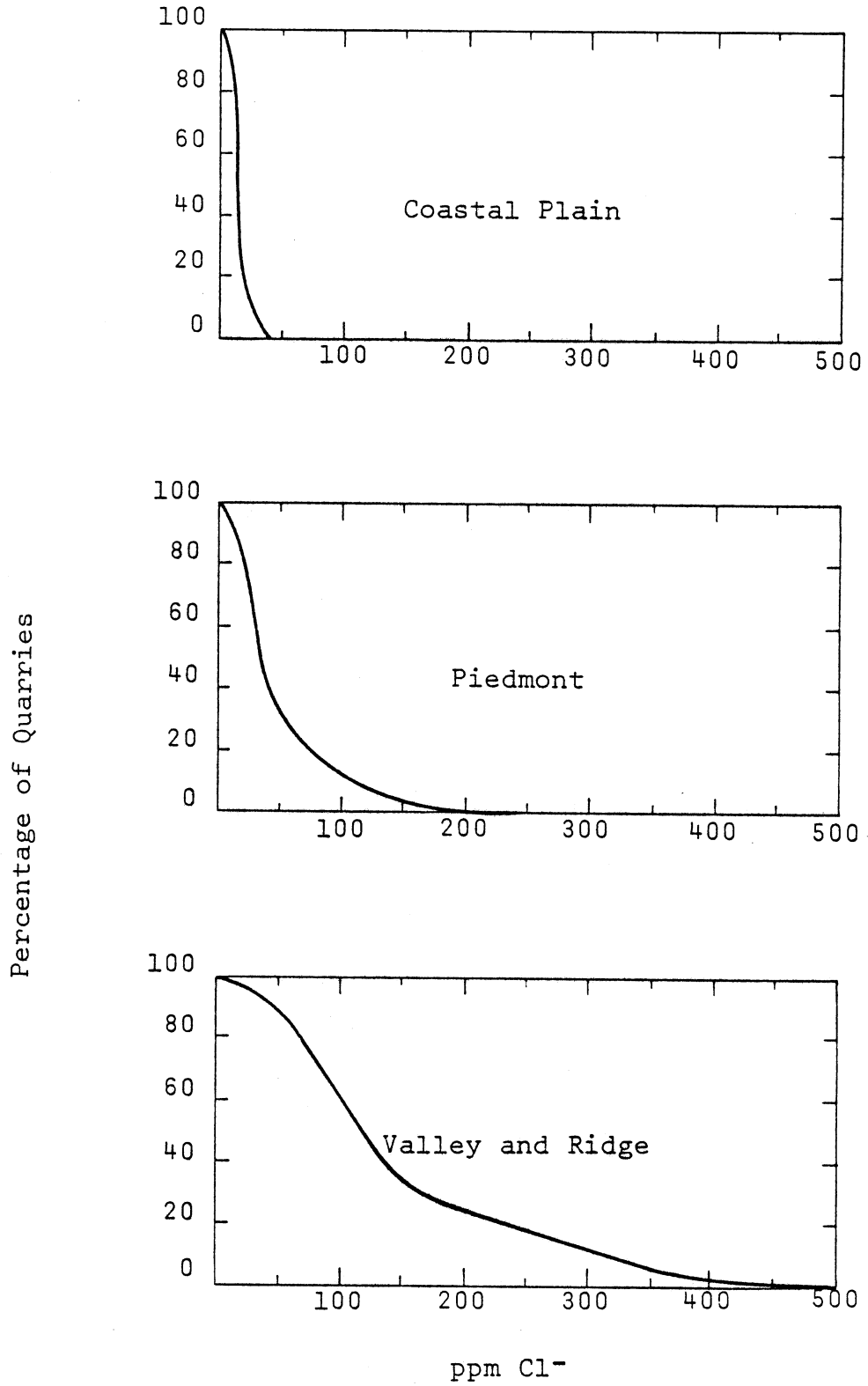


Figure 2. Percentage of quarries with average total chloride exceeding certain concentration.

TABLE 4

Statistical Summary of Chloride Contents of Aggregates From
the Three Geological Provinces in Virginia

	Valley and Ridge	Piedmont	Coastal Plain
Average total chloride (ppm)	Low	20	20
	High	240	40
	Grand Mean	60	20
Average water-soluble chloride (ppm)	Low	10	10
	High	30	30
	Grand Mean	20	20
Water-soluble chloride: total chloride	Low	0	0
	High	1.0	1.0
	Grand Mean	0.4	0.6

TABLE 5

Comparison of the Chloride Contents Observed in Some Existing Concrete Bridge Decks and the Corresponding Coarse Aggregates Used in Construction.

Bridge	Coarse Aggregate Source	Total Chloride Contents, ppm	
		at 4½" depth of deck(a)	in Aggregates(b) Low High
2	VR-54	230	130 340
4	VR-25	400	160 490
5	VR-25	370	160 490
14	VR-25	400	160 490
16	VR-25	560	160 490
8	P-1	120	40 80
11	P-5	160	50 50
17	P-5	100	50 50
1	C-1	80	10 30
6	C-1	60	10 30
15	C-5	60	40 40

(a) Adjusted to ppm in aggregate weight based on the known coarse aggregate contents in the original concrete mix as reported by Newlon.(12)

(b) As observed in this survey and given in Tables 1-3.

It is presently recommended by federal authority that when surveying the condition of a concrete bridge deck by chloride analysis, and if it is not known what aggregates were used in its construction so that the same aggregates can be analyzed for their chloride content (which will be used to adjust the corrosion threshold value to account for the chloride that was already in the deck prior to service exposure), several concrete samples must be taken from about a 6-in (15.2-cm) depth through a sound concrete area and analyzed for their chloride contents. The resulting values will then be taken to represent the chloride contributed by the aggregates. Based on the agreement shown in Table 5, it can be concluded that this current federal recommendation constitutes a sound practice.

This presence of relatively high concentrations of chloride in the sedimentary rocks in the Valley and Ridge province is not unexpected. The province, also known as the Appalachian Valley, is a large geologic trough (Appalachian geosyncline) formed by

the gradual subsidence of a natural belt in the eastern part of North America and extending at least from Newfoundland to Alabama.(13) The abundant marine fossils found in these sedimentary rocks indicate that a shallow interior sea partially covered the trough at numerous times in the past, and the limestone and dolomite were precipitated in this ancient seaway from limy material, derived in part in solution from the bordering lands, throughout much of the Paleozoic era. During precipitation and subsequent deposition of the limestone and dolomite precipitate some chloride, mostly as the salt of sodium, was trapped in pores within the mass of the limy precipitate.

A close examination of the different geologic formations from which quarries in the Valley and Ridge province are mining indicates generally that the Shady, Elbrook, Conococheague, and Beekmantown formations produce aggregates with the highest chloride concentrations. These formations happened to be relatively close to each other in geologic ages and spanned only about 100 million years between the Cambrian and Ordovician periods. It is uncertain whether this correspondence was caused by the existence then of geologic conditions favorable to the entrapment of chloride.

With the exception of a few aggregate sources, especially P-10, the remaining sources in the Piedmont showed relatively low chloride levels. Again, this is not unexpected, nor were the relatively lower chloride levels shown by sand and gravel from the Coastal Plain. The exceptionally high chloride levels found in the granite gneiss produced by P-10 (Table 2) probably come from chloride-bearing minerals known to occur in some silicate rocks.

When the total chloride content of an aggregate is high, it doesn't necessarily mean that the aggregate will contribute to corrosion when used in reinforced concrete, because the chloride may not be completely available. To provide an estimate of the chloride availability, all aggregates were also analyzed for their water-soluble chloride contents, which are presented in Tables 1-3 along with the ratios of average water-soluble chloride to average acid-soluble, or total chloride, for each aggregate source. A statistical summary of these data is shown in Table 4.

Collectively, the grand mean water-soluble chloride contents are 70 ppm, 20 ppm, and 20 ppm for the Valley and Ridge, the Piedmont, and the Coastal Plain, respectively. Aggregates from the Valley and Ridge province exhibited water-soluble chlorides ranging from as low as 20% to as high as 100%, with a grand mean of 50%, of the total chloride. The corresponding values for the aggregates from the Piedmont and Coastal Plain are comparable to those of the Valley and Ridge.

Individual examinations of all aggregate sources listed in Table 1 indicated that, generally, the sources that have high total chloride contents have low percentages of water-soluble chloride. This would mean that only a small amount of the total chloride may be leached out of the aggregates to induce corrosion and, therefore, these aggregates are safe to use, if the test condition in the standard analysis procedure for water-soluble chloride⁽⁷⁾ approximates the leaching condition in which aggregates are normally subjected to in a reinforced concrete bridge deck. As described earlier, it is obvious that the procedure doesn't; however, it provides a vigorous and accelerated leaching of the chloride through boiling of the ground aggregate in distilled water, and therefore may provide an estimate of the upper limit of, or maximum, water-soluble chloride.

Based on the present state of knowledge on the corrosion of reinforcing steel in concrete, American Concrete Institute Committee 201 suggests⁽¹⁴⁾ the following limits for water-soluble chloride ion concentrations in concrete prior to service exposure, expressed as a percentage by weight of cement:

- | | |
|--|-------|
| 1. Prestressed concrete | 0.06% |
| 2. Conventionally reinforced concrete
in a moist environment and exposed
to chloride | 0.10% |

If a resulting concrete has a water-soluble chloride level less than the applicable limit listed above, then the probability of corrosion of the rebar caused by chloride contained in the concrete mix will be low. Since even the highest water-soluble chloride concentration of 170 ppm (based on the weight of aggregate) observed in this survey will not result in a concrete, either conventional or prestressed, exceeding the above limits, it can be concluded that not one aggregate surveyed is likely to contribute to the corrosion of the rebar in whatever concrete it is used.

As mentioned earlier, in the formulation of decisions regarding the repair of existing bridge decks, the corrosion threshold value is 510 ppm total chloride, assuming that as low as 50% of the total chloride (i. e., 255 ppm) is water soluble. Based on current federal recommendations, if the aggregate used in the deck being evaluated shows a total chloride content greater than 128 ppm and the soluble chloride is less than 50%, then the threshold value of 510 ppm total chloride should be adjusted upward to reflect a significant contribution of insoluble chloride from the aggregate. An examination of the survey results shows that when concrete bridge decks made with aggregates from 17 sources listed in Table 1 and another 4 sources in Table 2 are evaluated for corrosion problems, the recommended adjustment to the corrosion threshold value applies.

CONCLUSIONS

1. Among the 104 aggregate sources surveyed, the sedimentary rocks (mainly limestone and dolomite) of the Valley and Ridge province contain the highest amounts of chloride, both total and water-soluble. Then come the igneous and metamorphic rocks of the Piedmont and, lastly, the sand and gravel of the Coastal Plain, in order of decreasing chloride contents.
2. The chloride contents in most of the igneous and metamorphic rocks and all of the sand and gravel tested are generally so low that they can be safely ignored.
3. Although some of the dolomite and limestone showed relatively high chloride contents, none of these aggregates are likely to cause corrosion of the rebar in concrete, because none of these will result in a concrete exceeding the limits for chloride ion concentration, prior to service exposure, suggested by the American Concrete Institute and based on the current knowledge of rebar corrosion in concrete.
4. Twenty-one sources showed average total chloride contents greater than 128 ppm, with less than 50% of the total being water soluble. When concrete bridge decks made with aggregates from any of these sources are being evaluated for corrosion problems, the corrosion threshold value of 510 ppm total chloride should be adjusted upward.

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REFERENCES

1. Clear, K. C., "Evaluation of PCC for Permanent Bridge Deck Repair", Federal Highway Administration, FHWA-RD-74-5, February 1975.
2. Hime, W. G., and B. Erlin, "'Chloride-Free' Concrete", Journal of the American Concrete Institute, Vol. 74 (1977) p. N7.
3. Reynolds, J. W., Memorandum, Virginia Highway & Transportation Research Council, June 1975.
4. "Do's & Don'ts of Sampling", Federal Highway Administration, March 1978.
5. Newlon, H. H., Jr., W. C. Sherwood, and M. A. Ozol, "Potentially Reactive Carbonate Rocks, Progress Report No. 8 - A Strategy for Use and Control of Potentially Reactive Carbonate Rocks Including an Annotated Bibliography of Virginia Research", Virginia Highway and Transportation Research Council, VHTRC 71-R41, June 1972.
6. Berman, H. A., "Determination of Chloride in Hardened Portland Cement Paste, Mortar, and Concrete", Federal Highway Administration, FHWA-RD-72-12, September 1972.
7. Clear, K. C., and E. T. Harrigan, "Sampling and Testing for Chloride Ion in Concrete", Federal Highway Administration, FHWA-RD-77-85, August 1977.
8. Clemeña, G. G., J. W. Reynolds, and R. McCormick, "Comparative Study of Procedures for the Analysis of Chloride in Hardened Concrete", Virginia Highway and Transportation Research Council, VHTRC 77-R7, July 1976. (This report has been reprinted as Report No. FHWA-RD-77-84, Federal Highway Administration, August 1977).
9. Clemeña, G. G., J. W. Reynolds, and R. McCormick, "Gran Method of Endpoint Determination in Chloride Analysis by Potentiometric Titration", Transportation Research Record 651, pp. 1-6, 1977.
10. Gooch, E. O., R. S. Wood, and W. T. Parrott, "Sources of Aggregate Used in Virginia Highway Construction", Virginia Division of Mineral Resources, Charlottesville, Virginia, 1960.
11. Clarke, F. W., "Data of Geochemistry", U. S. Geological Survey, Bulletin 770, 1924.

12. Newlon, H., "Relationship Between Properties of Hardened Concrete and Bridge Deck Performance in Virginia", Virginia Highway and Transportation Research Council. (In print)
13. Butts, C., "Geology of the Appalachian Valley in Virginia", Parts I and II, Virginia Geological Survey, Bulletin 52, 1940.
14. "Guide to Durable Concrete", Journal of American Concrete Institute, Vol. 74, pp. 573-609.

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