Evaluation of Pine Bluff Bypass Concrete Pavement in Pine Bluff, Arkansas

Petrographic Evaluation

ASR Development and Deployment Program
Field Application and Demonstration Projects

U.S. Department of Transportation
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16. Abstract

This report presents the findings of the petrographic examination of five concrete cores extracted from sections of the Pine Bluff By-Pass concrete pavement by the Arkansas DOT in 2011. The evaluation mainly consisted of the *Damage Rating Index* (DRI), a method that provides a semiquantitative assessment of the damage in concrete based on a count of petrographic features of deterioration generally associated with alkali-silica reaction (ASR).

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1 Introduction

This report presents the findings of the petrographic examination of five concrete cores extracted from sections of the Pine Bluff By-Pass concrete pavement by the Arkansas DOT in 2011. The evaluation mainly consisted of the *Damage Rating Index* (DRI), a method that provides a semi-quantitative assessment of the damage in concrete based on a count of petrographic features of deterioration generally associated with alkali-silica reaction (ASR).

2 Field Work – Extraction of Cores

Coring was conducted under the supervision of the Arkansas DOT. Table 1 presents cores number, location, and length.

Table 1 : Cores provided for petrographic examination by the Arkansas DOT

Job #	Core number	Location	Core location	Condition	Length (cm)
D02153, Jefferson County	Ark-1	North Bound, Log mile 42.01	8.0' Highway 530	Core in 1 section	28.5
	Ark-2	North Bound, Log mile 38.5	7.5' Highway 531	Core in 1 section	28.5
	Ark-3	South Bound, Log mile 41.4	6.7' Highway 532	Core in 1 section	28
	Ark-4	South Bound, Log mile 42.05	7.6' Highway 533	Core in 2 section	28
	Ark-5	North Bound, Log mile 36.0	8.7' Highway 534	Core in 1 section	28.5

3 Laboratory Testing of Cores – Damage Rating Index (DRI)

The concrete cores were sent to Dr. Benoit Fournier at Laval University, Quebec, Canada in April 2011. The five cores were first examined macroscopically and photographed. Cores that showed significant cracking were glued with epoxy, cut in two axially and one of the two surfaces thus obtained was polished.

The portable hand-polishing device (Figure 1) uses a series of diamond-coated rubber disks to ensure progressive polishing from coarser to finer sizes [i.e. from disks no. 50 (coarse), 100, 400, 800, 1500 to 3000 (very fine)]. The polished sections are then photographed and a grid is drawn on the section, which includes a minimum of 200 grid squares, 1 cm by 1 cm (0.4 by 0.4 in) in size (Figure 2).

Figure 1: Polishing process of the concrete specimens for the Gel Pat Test.

Figure 2: One cm by one cm (0.4 in. by 0.4 in.) grid drawn at the surface of the polished concrete section for petrographic examination using the DRI method.

Each grid square is then examined under the stereomicroscope to determine the *Damage Rating Index* (DRI) (Figure 3). Grattan-Bellew (1992) and Dunbar and Grattan-Bellew (1995) indeed described a method to evaluate the condition of concrete by counting the number of typical petrographic features of ASR on polished concrete sections (15x magnification) (Table 2). The *Damage Rating Index* represents the normalized value [to 100 cm^2 (16 in^2)] of the presence of the above petrographic features after the count of their abundance over the surface examined has been multiplied by weighing factors representing their relative importance in the overall deterioration process. Table 2 also gives the weighing factors originally proposed by Dr. Grattan-Bellew from the National Research Council of Canada and used in this study.

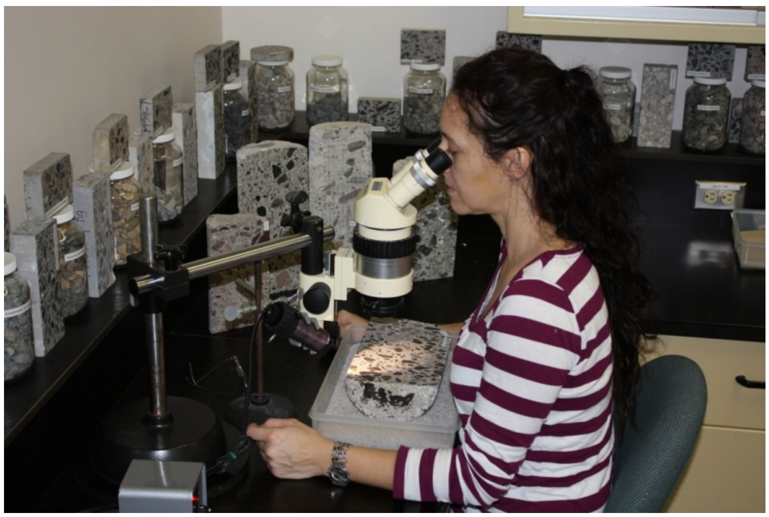


Figure 3: Examination of the polished concrete section under the stereomicroscope for the determination of the *Damage Rating Index*.

Figure 4 gives examples of the petrographic features that are quantified as part of the process. The DRI was originally developed to quantify the damage in concrete affected by ASR in the coarse aggregate particles. We have thus adopted a procedure that consists in evaluating the presence of petrographic features of ASR in aggregate particles of minimum 2 mm (0.08 in) in size. However, in the case of the Arkansas cores, the preliminary examination of the polished sections revealed that signs of ASR were actually present in the coarser fraction of the fine aggregate (sand) of the concrete (chert particles). For that reason, we modified slightly the DRI procedure to allow the identification of the petrographic signs of deterioration in aggregate particles down to 1 mm (0.04 in) in size.

Table 2: Petrographic Features and Weighing Factors for the DRI (*Grattan-Bellew and Mitchell 2006*).

Petrographic feature	**Abbreviation**	**Weighing factors**
		Grattan-Bellew and Mitchell 2006
Cracks in coarse aggregate	CrCA	x 0.75
Open crack in coarse aggregate	OCrCA	x 4.0
Crack with reaction products in coarse aggregate	Cr+RPCA	x 2.0
Coarse aggregate debonded	CAD	x 3.0
Reaction rims around aggregate	RR	x 0.5
Cracks in cement paste	CrCP	x 2.0
Cracks in cement paste with reaction products	Cr+RPCP	x 4.0
Air voids lined or filled with reaction products	RPAV	x 0.50
Disaggregated (aggregate) particle	DCA	---

There is currently no rating system for the DRI values that correspond to concrete affected to a low, moderate or severe degree by ASR. However, our experience is such that values below 200-250 are indicative of a low degree of reaction / deterioration, DRIs of 200-500 correspond to moderate degree of reaction, and DRIs in excess of about 500-600 represent a high to very high (DRI > 1000) degree of ASR. It is important to mention, however, that since the DRI is not a standardized method, and values can vary significantly from one petrographer to another.

4 Results of the Petrographic Examination

Appendix A shows images of the five cores in their "as-received" condition. Pictures of noticeable macroscopic features of deterioration/reaction are also presented, particularly cracking with alkali-silica reaction product in reacted (chert) sand particles, as well as air voids in the cement paste filled with alkali-silica reaction products.

Table 3 gives a summary of the petrographic observations (in terms of the typical crack width observed in the cement paste of the cores) and a rating of the extent of ASR in the concrete of the five polished sections examined as part of this investigation. The sections are illustrated in Figure 5, while the results of the DRI are summarized in Figure 6. Figure 7 illustrates the typical petrographic features observed in this set of cores. The detailed results of DRI, including micrographs of the petrographic features in the cores examined, are given in the Appendix B.

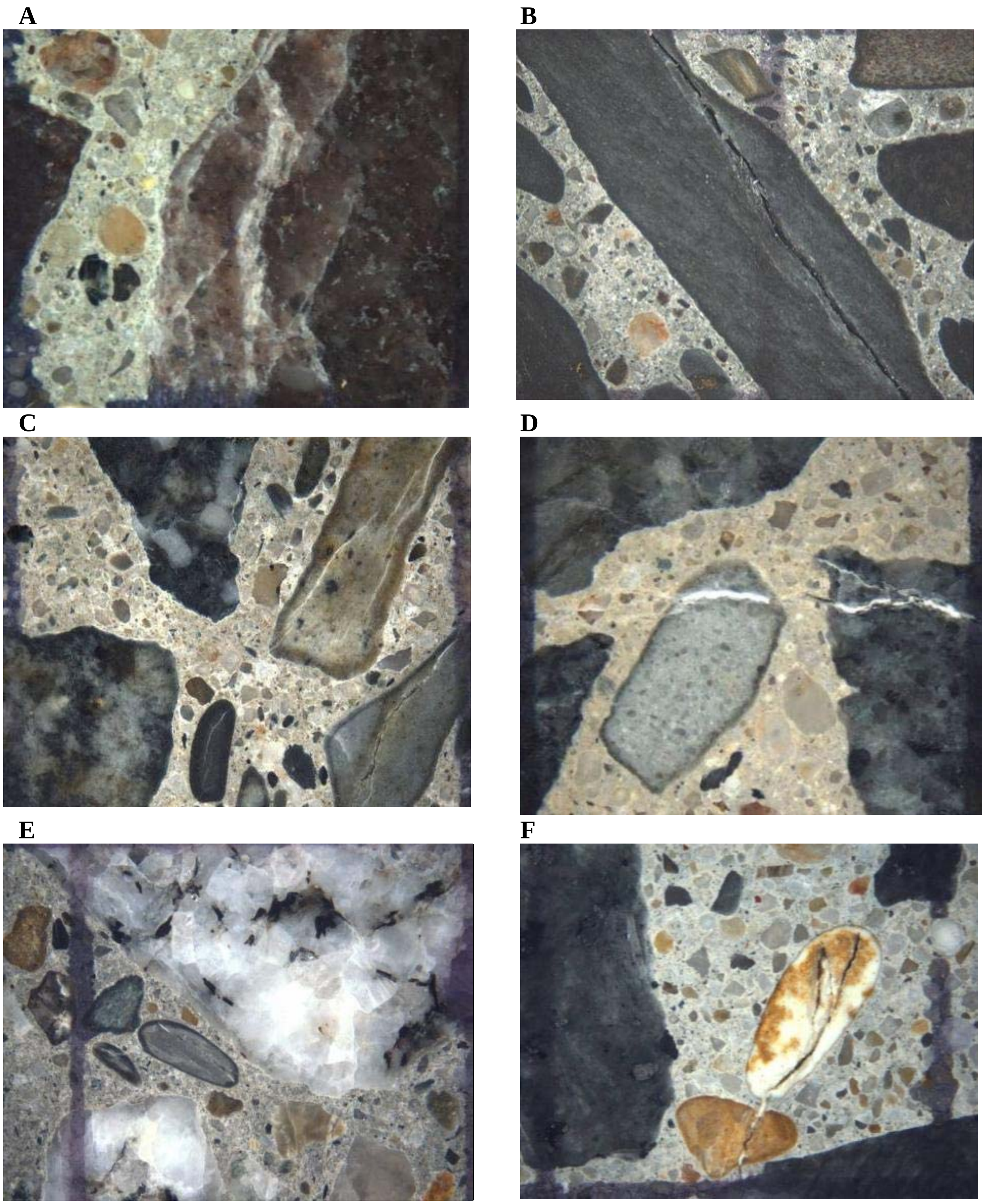
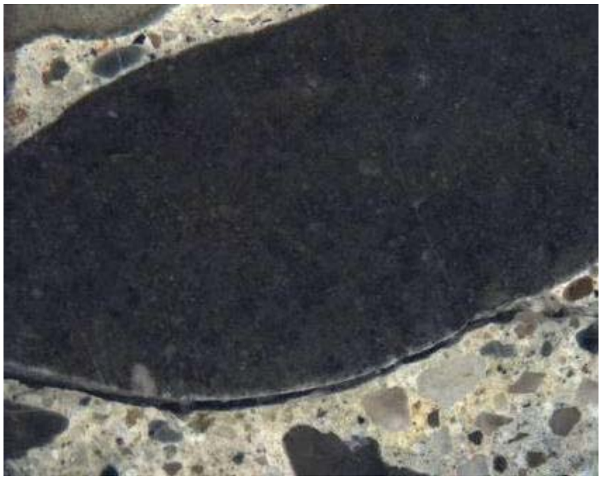


Figure 4: Examples of typical petrographic features of deterioration due to ASR identified on polished concrete sections as part of the *Damage Rating Index* (DRI). A&B: Cracks in coarse aggregate particles (A- tight cracks; B- open cracks); C&D: Cracks with reaction products in the coarse aggregate particles; E&F: Cracks with reaction products in fine aggregate particles.

G



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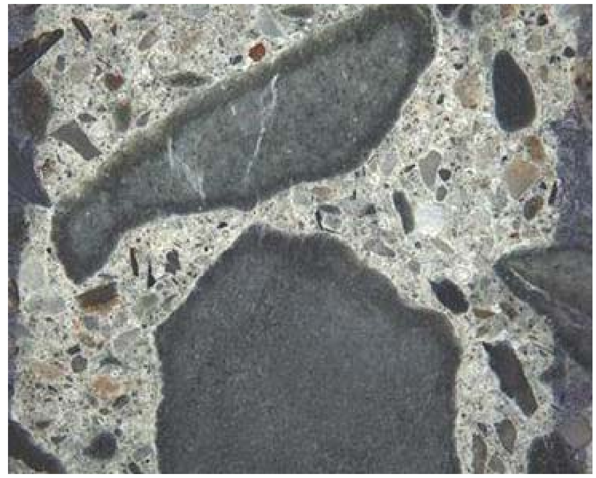

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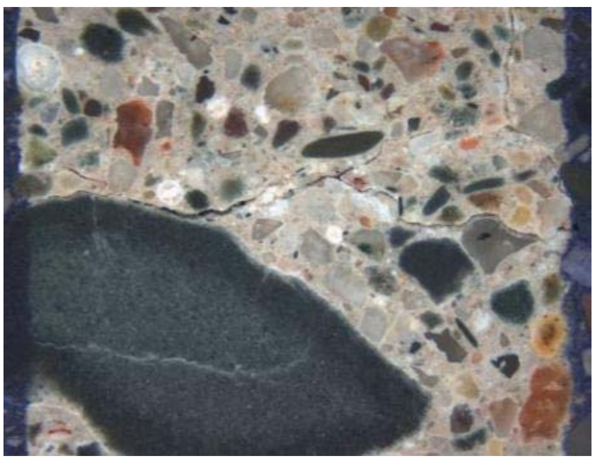

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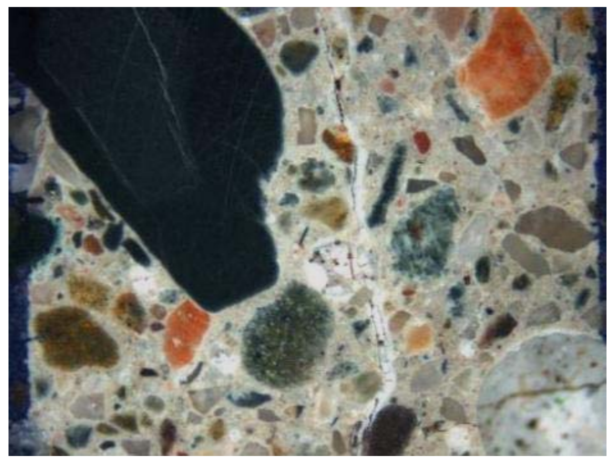

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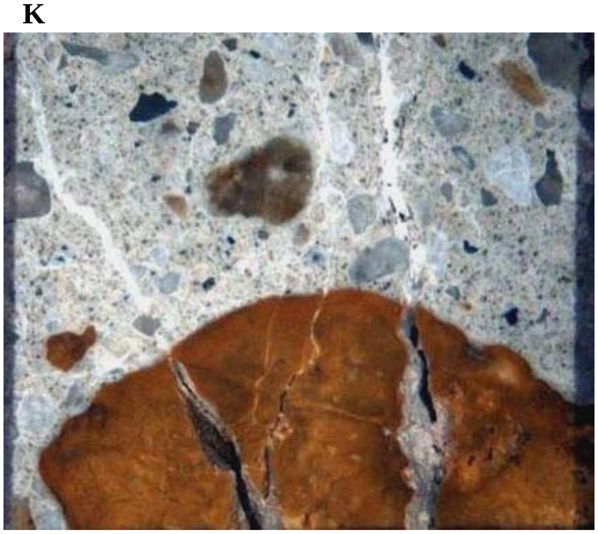

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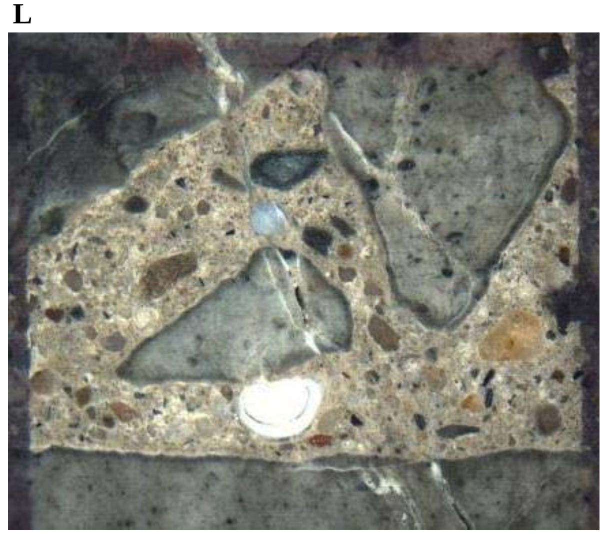


Figure 4 (cont'd): G: Debonded coarse aggregate particle; H: Reaction rims around reactive coarse aggregate particles; I: Cracks in the cement paste; J-L: Cracks with reaction products in the cement paste; L: Whitish and glassy alkali-silica reaction products in air voids of the cement paste.

Table 3: Summary of the macroscopic observations on the polished cores from the Arkansas pavement

Sample	DRI	Noticeable features, including extent of cracking and typical cracks width in the cement paste (mm)	Extent / Degree of ASR
Ark-1	**254**	• Significant cracking in the cement paste (crack width from 0.15 mm to 0.40 mm) with or without reaction products. • One surface crack penetrates about 40mm into the concrete. • One major crack (about 0.40mm in width) roughly parallel to the surface and at about 130 mm in depth; the crack was glued with epoxy prior to cutting and polishing operations. • One significant crack (0.20mm in width) roughly parallel to the surface (20-30 mm in depth).	Low
Ark-2	**344**	• Significant cracking in the cement paste (crack width from 0.3 mm to 0.5 mm) with or without reaction products. • One surface crack penetrates about 30mm into the concrete. • Significant cracks (ranging from 0.10 to 0.20mm in width) are observed roughly parallel to the surface and at the following depths: 90 and 170mm. • One major crack (about 0.40mm in width) ~ parallel to the surface and at about 130 mm in depth; the crack was glued with epoxy prior to cutting and polishing operations.	Low to Moderate
Ark-3	**397**	• Significant cracking in the cement paste (crack width from 0.25 mm to 0.3 mm) with or without reaction products; • One surface crack penetrates about 10mm into the concrete.	Moderate
Ark-4	**489**	• Significant cracking in the cement paste (crack width from 0.2 mm to **2 mm**) with or without reaction products. • One surface crack penetrates about 20mm into the concrete. • Several significant cracks (ranging from 0.10 to 0.20mm in width) are observed roughly parallel to the surface and at various depths: 10-20, 30-40, 60, 80-85, 135 and ~200mm. Cracks often run at the interface between the cement paste and the coarse aggregate particles. • Two cracks (i.e. 60 and 135 mm in depth) were glued with epoxy prior to cutting and polishing operations.	Moderate
Ark-5	**326**	• Significant cracking in the cement paste (crack width from 0.1 mm to 0.5 mm) with or without reaction products. • One surface crack penetrates about 20mm into the concrete. • Significant cracks (about 0.10mm to 0.20 in width) are observed roughly parallel to the surface and at various depths: 15-20, 70-80 and 180-200mm.	Low to Moderate

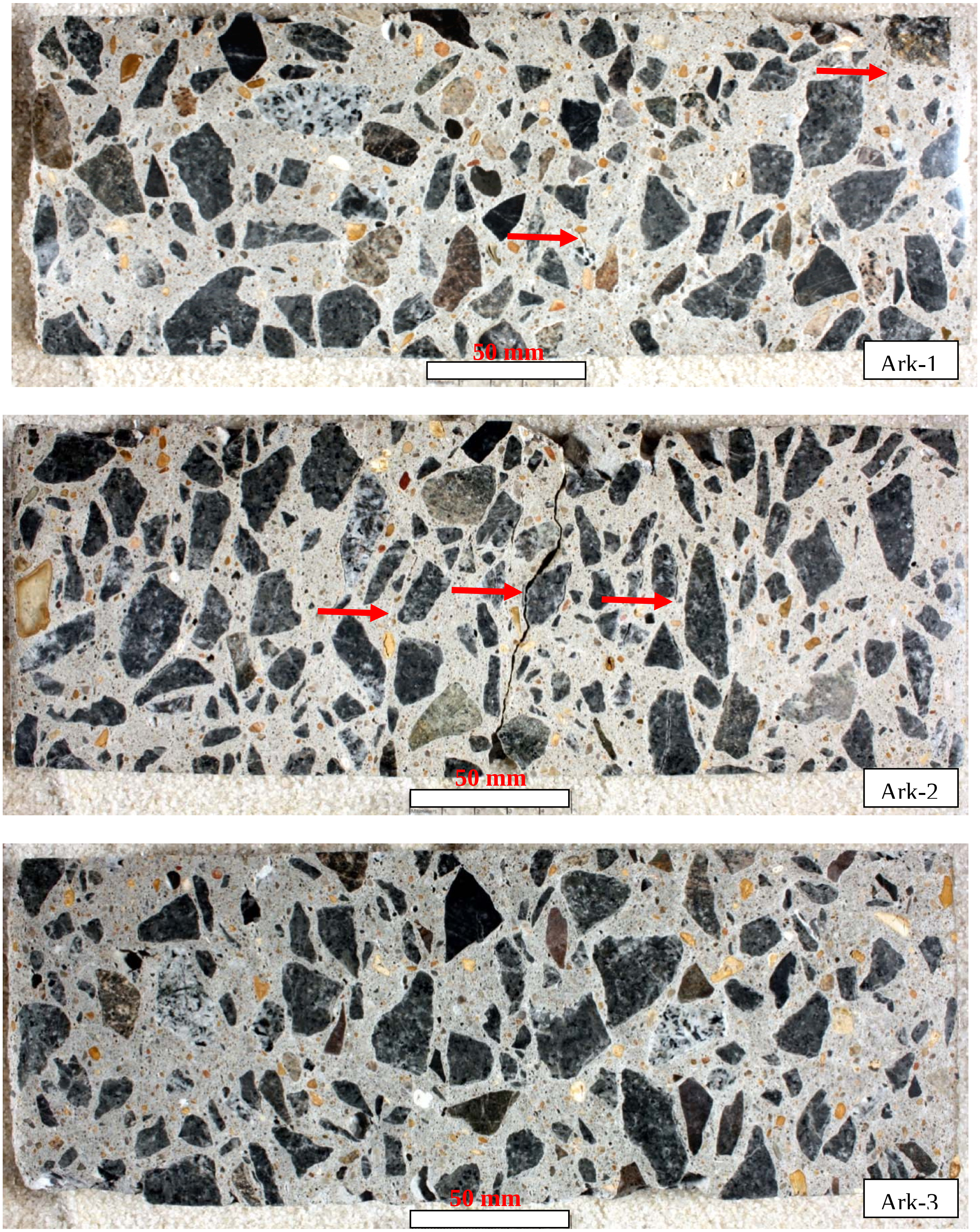
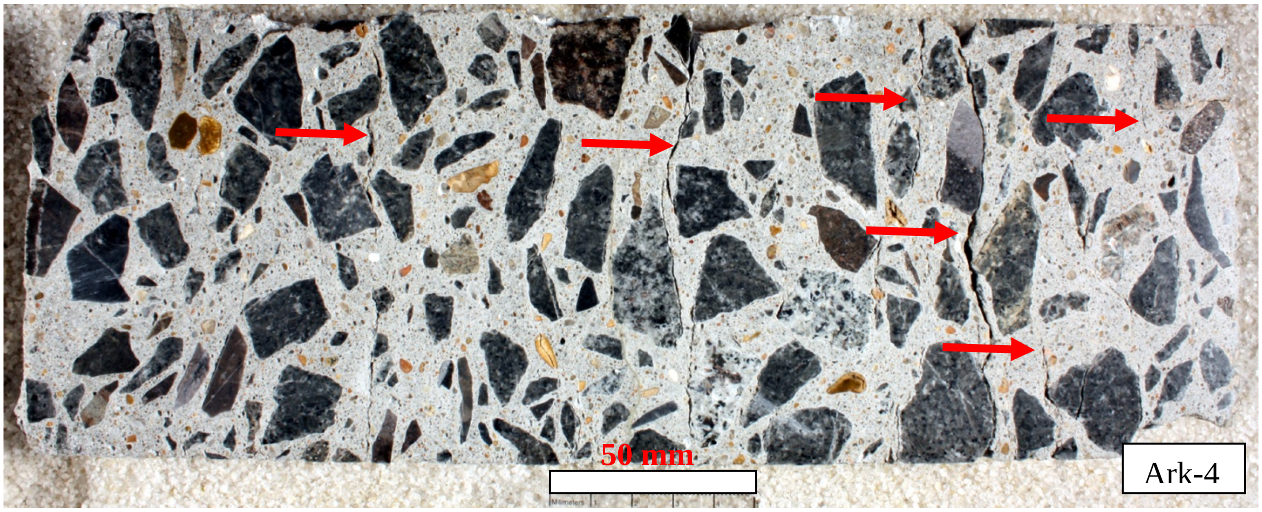


Figure 5: Polished concrete sections from Arkansas DOT (the pavement surface is on the right side). Significant cracks are identified with red arrows.



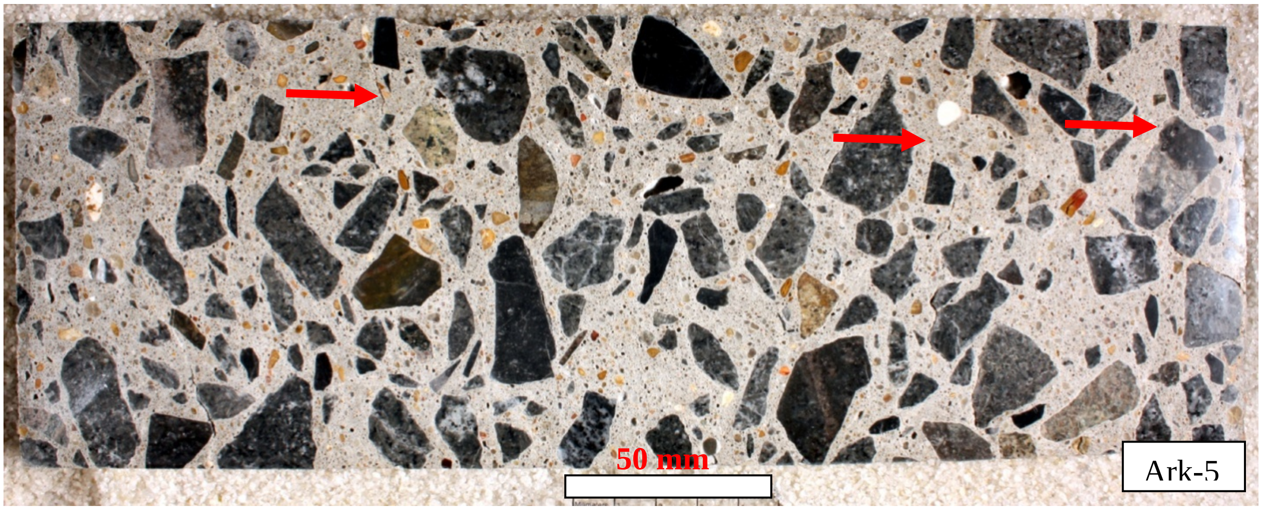


Figure 5 (cont'd) : Polished concrete sections from Arkansas DOT(the pavement surface is on the right side)

Sample	Cracks in the aggregate particles			Crack in the cement paste		CAD	RR	RPAV	DRI
	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP				
Ark-1	86	0	45	75	13	17	13	4	**254**
	34	*0*	*18*	*30*	*5*	*7*	*5*	*2*	*100*
Ark-2	89	8	51	84	62	39	10	2	**344**
	26	*2*	*15*	*24*	*18*	*11*	*3*	*1*	*100*
Ark-3	87	9	75	89	65	55	15	2	**397**
	22	*2*	*19*	*22*	*16*	*14*	*4*	*1*	*100*
Ark-4	80	5	53	159	59	119	9	3	**489**
	16	*1*	*11*	*33*	*12*	*24*	*2*	*1*	*100*
Ark-5	91	2	51	74	62	33	11	2	**326**
	28	*1*	*16*	*23*	*19*	*10*	*3*	*1*	*100*

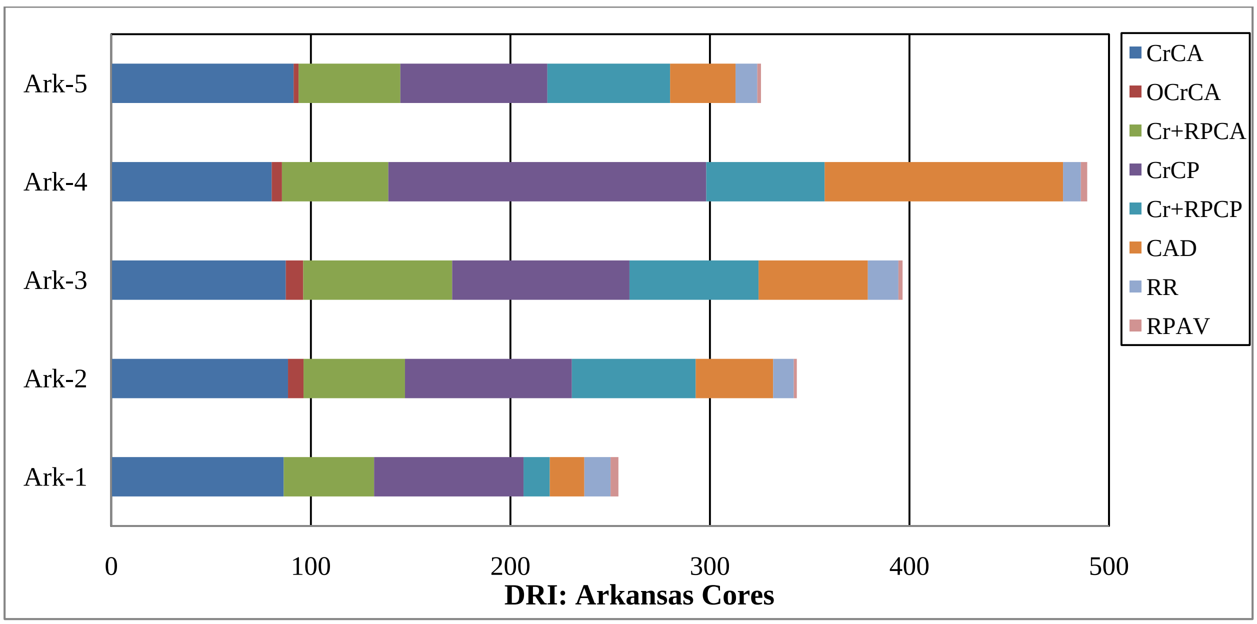


Figure 6: Results of the *Damage Rating Index* (DRI) for the Arkansas DOT cores. The colored cells give the proportions (or contribution in %) of each petrographic feature to the DRI value.

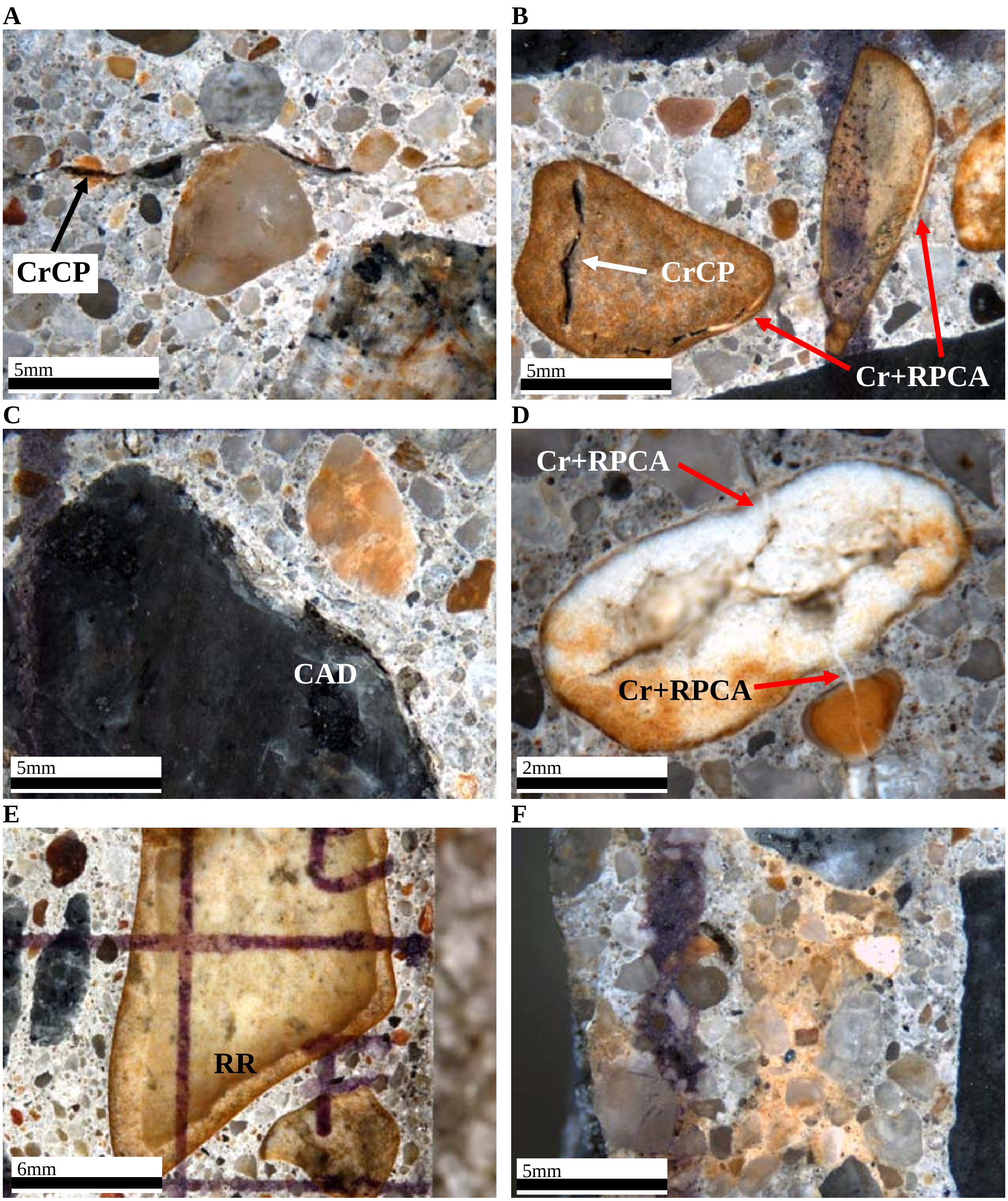


Figure 7 : Example of the petrographic features observed in the Arkansas concrete cores; A: Crack in the cement paste (CrCP); B: Open crack (OCrCA) and crack with alkali-silica reaction product in the coarser fraction of the fine aggregate (chert) (Cr+RPCA); C: Coarse aggregate debonded (CAD); D: Reacted aggregate particle (coarse fraction of the sand) and cracks with reaction product in the sand grain (Cr+RPCA) and in the cement paste (Cr+RPCP); E: Reaction rim (RR) on a particle of the coarse fraction of the sand; F: carbonation of the cement paste.

As illustrated in the Figures 5 to 7, the polished concrete sections of the Arkansas cores show *Damage Rating Indices* ranging from 254 to 489, suggesting low to moderate degree of deterioration/damage due to ASR. As indicated in the Figure 6, the highest contributor to the DRI corresponds to *Cracks in the cement paste with or without reaction product (CrCP - Cr+RPCP)* (total of 35 to 45% of the DRI values). Widths of the cracks in the cement paste vary from 0.1 mm (0.004 in) in core Ark-1 to 2 mm (0.08 in) in core Ark-4. Those cracks are not always filled with ASR reaction product and show some signs of carbonation.

The polished sections also show a fair amount of *Cracks in the aggregate particles (CrCA),* the second most important contributor to the DRI values for this set of cores (16 to 34% of the DRI values). The coarse aggregate [5 to 20 mm (0.2 to 0.8 in)] in the Arkansas cores essentially consists in a granitic gneiss and shows no evidence of ASR, as there is no cracking in the above particles filled with secondary reaction products (ASR gel) and/or extending into the cement paste (at least at the magnification (15x) used in the DRI test). The internal cracking observed in the gneiss particles is thought to be mainly related to aggregate processing operations. Some of the coarse aggregates show signs of debonding (7 to 14% of the DRI values).

Signs of ASR were observed in chert particles present in the coarser fraction [> 1 mm (>0.04 in)] of the sand, i.e. presence of ASR gel in the aggregate particles (they were classified in the *Cr+RPCA* feature) (<u>11 to 19% of the DRI values</u>) (e.g. Figure 7B), reaction (or weathering) rims (*RR*) (2 to 5% of the DRI values)(e.g. Figure 7E), and cracking in the cement paste with reaction products associated to reactive sand particles (<u>5 to 19% of the DRI values</u>) (e.g. Figure 7D). Some *reacted* sand particles (i.e. signs of degradation) have been observed in those cores (e.g. Figure 7D).

Significant cracking, roughly parallel to the surface, was observed at different depths in four out of the five cores examined (see Table 3 and Figure 5). The cracks generally range from 0.10 to 0.20 mm (0.004 to 0.008 in.) in width. Some of those cracks were glued prior to the cutting and polishing operations.

Signs of carbonation were observed along surface cracks penetrating into the concrete; depth of carbonation is generally limited to the first 5 mm (0.2 in.) from the surface of the concrete.

5 Conclusion - Summary of Findings

This report summarizes the results of the petrographic examination, using the *Damage Rating Index* method, of a set of five cores taken in a concrete pavement by the Arkansas DOT.

Damage Rating Indices ranging from 254 to 489 were obtained for the cores Ark 1 to Ark5, thus suggesting low to moderate degree of deterioration/damage due to ASR. Signs of alkali-silica reaction can be found in chert particles of the coarser fraction of the sand in the concrete. Typical petrographic features of ASR corresponds to cracking with ASR gel and reaction rims in the chert particles, as well as cracking in the cement paste with reaction products associated to the reactive chert particles. Tight/closed cracks were observed in several coarse aggregate particles, consisting of granitic gneiss. This cracking is thought to be associated to the aggregate processing operations and not to ASR.

6 References

Dunbar. P.A. and Grattan-Bellew, P.E. 1995. Results of damage rating evaluation of condition of concrete from a number of structures affected by AAR. *In* Proceedings of CANMET/ACI International Workshop on AAR in Concrete, Dartmouth, Nova Scotia, CANMET, Department of Natural Resources Canada, pp. 257-265.

Grattan-Bellew, P.E. 1992. Comparison of laboratory and field evaluation of alkali-silica reaction in large dams. *In* Proceedings of the First International Conference on Concrete Alkali-Aggregate Reactions in Hydroelectric Plants and Dams, September-October 1992, Fredericton, NB, Canada, 23p.

Grattan-Bellew, P.E. and Mitchell, L.D. 2006. Quantitative petrographic analysis of concrete – the damage rating index (DRI) method, a review. Proceedings of *Marc-André Bérubé Symposium on Alkali-Aggregate Reaction (AAR) in Concrete*, Montréal (Canada), May 2006, edited by B. Fournier, CANMET-MTL, 45-70.

Appendix A

Macroscopic description of the Arkansas Cores

Core: Ark-1

Figure A1: Core Ark-1

Figure A2: Details on the core Ark-1; reaction rim on a reactive particle of the fine aggregate.

Core: Ark-2

Figure A3: Core Ark-2

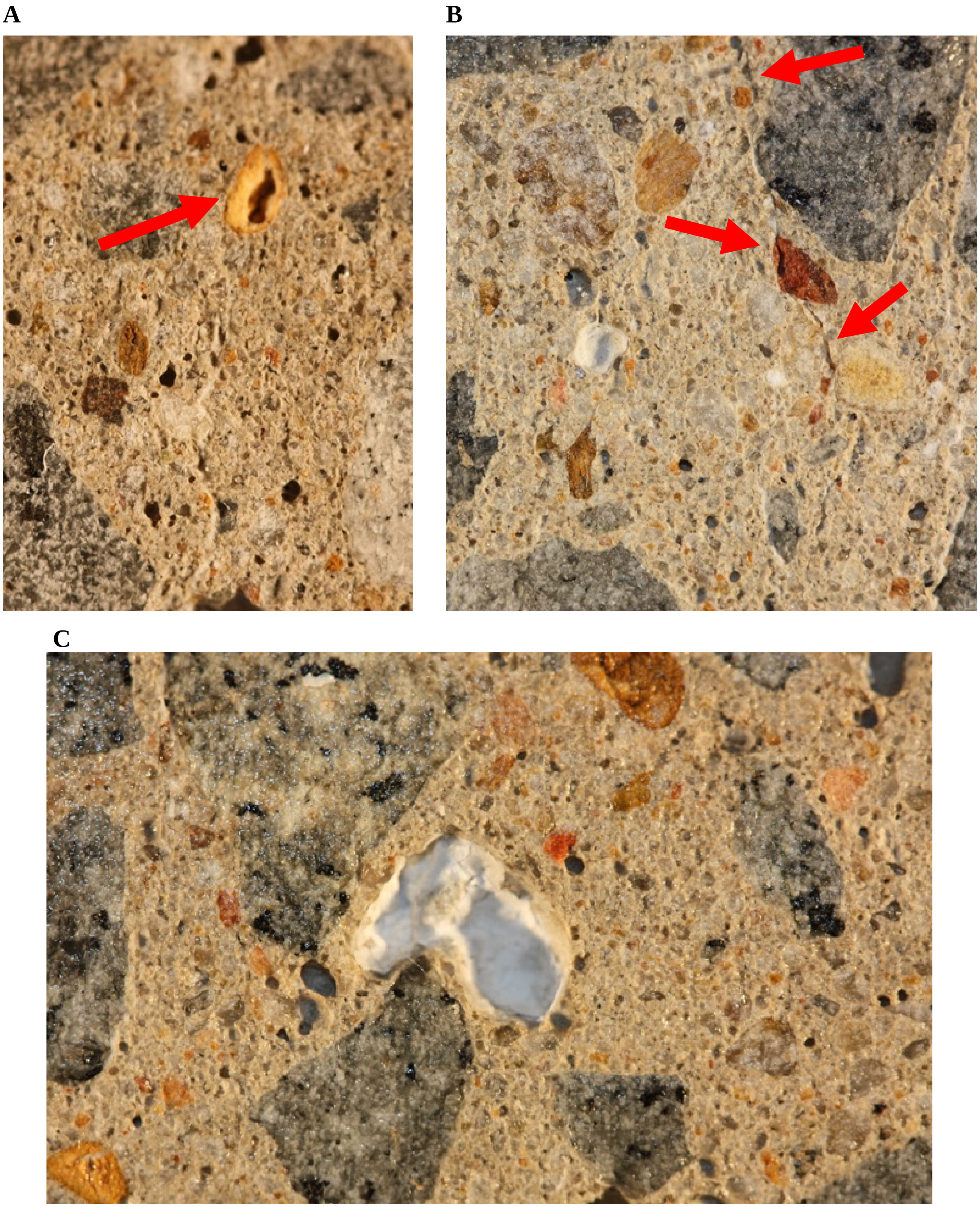
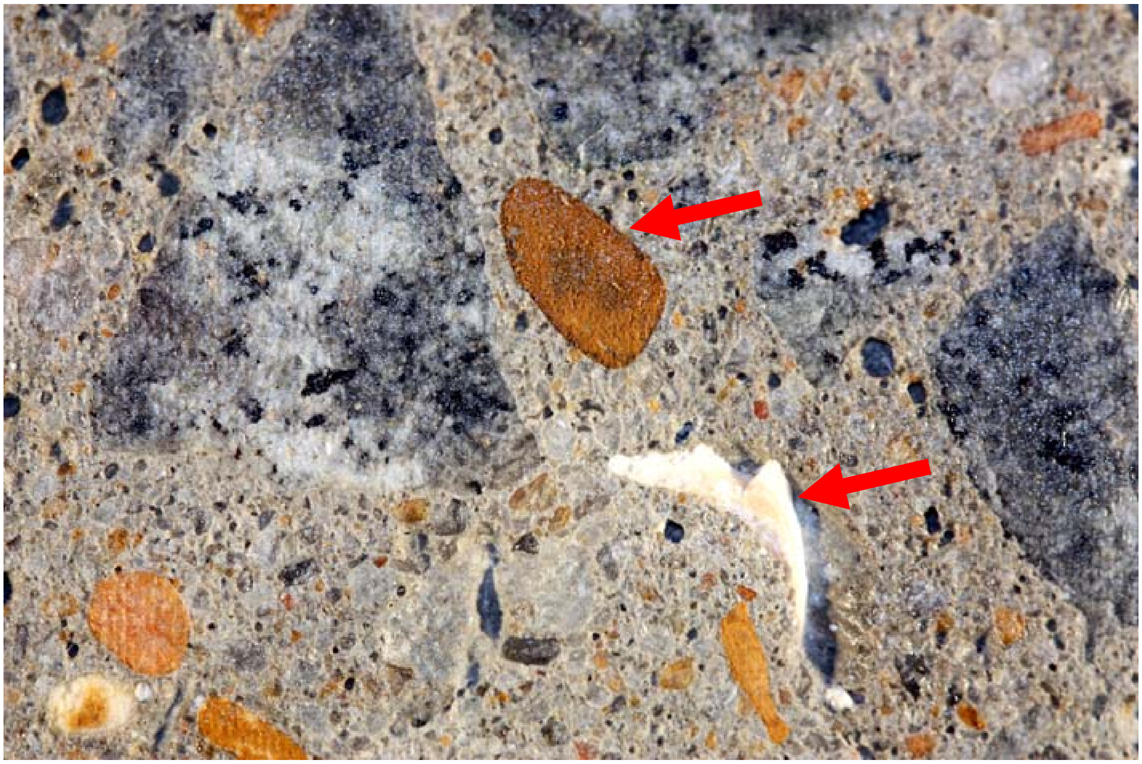


Figure A4: Details on core Ark-2. A: disaggregated/reacted aggregate particle; B: crack in the cement paste running through a reactive sand particle; C: air void filled with alkali-silica reaction product.

Core: Ark-3

Figure A5: Core Ark-3

A



B

Figure A6: Details on core Ark-3. A: reaction rim a around reacted sand particle and air void filled with alkali-silica reaction product; B: cracks with alkali-silica reaction product in a reactive particle of the fine aggregate.

Core: Ark-4

Figure A7: Core Ark-4

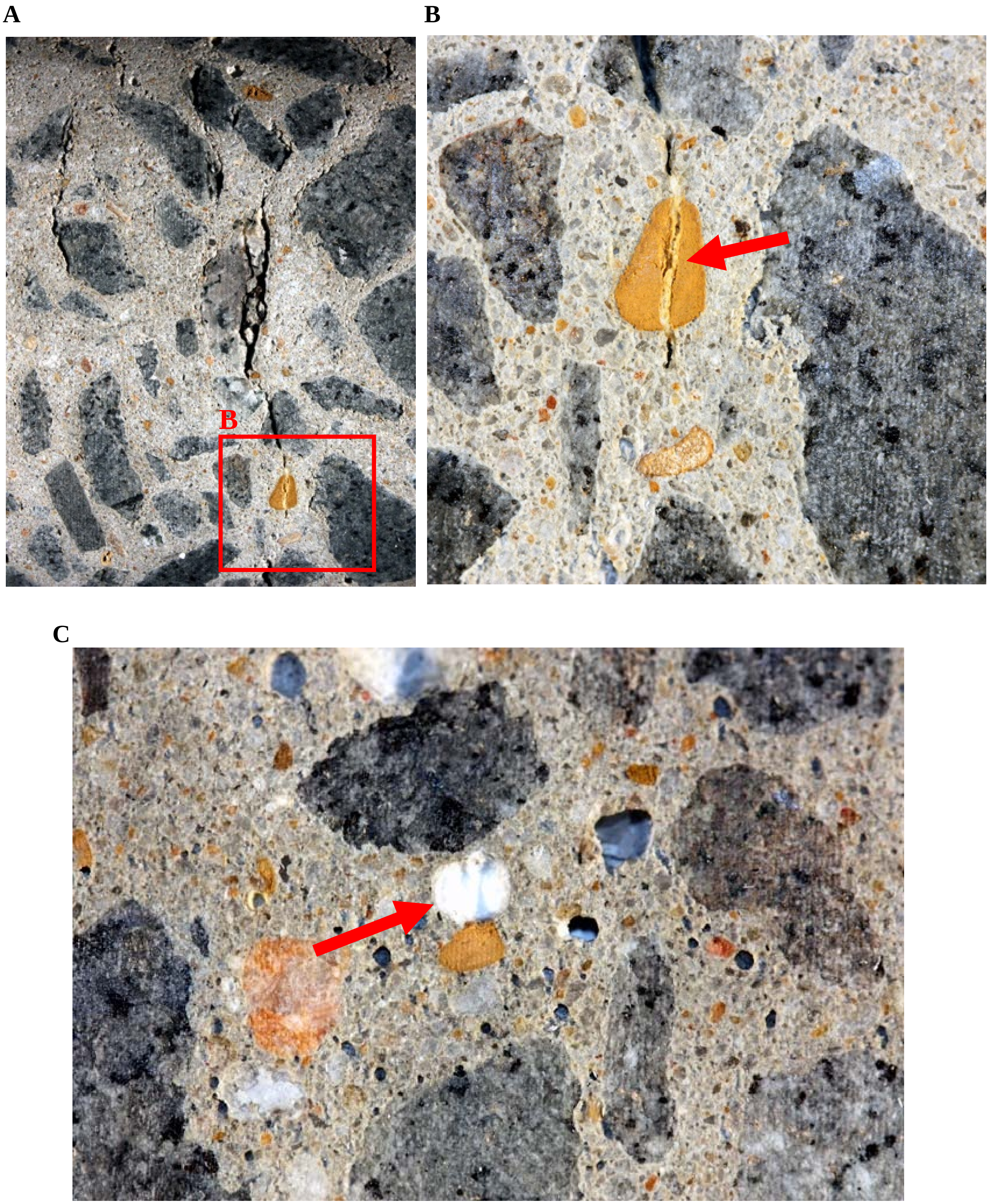


Figure A8: Details on core Ark-4. A: cracks in the cement paste running through a reactive sand particle; B: crack with alkali-silica reaction product in a reactive particle of the fine aggregate; C: air void filled with alkali-silica reaction product.

Core: Ark-5

Figure A8: Core Ark-5

A

B

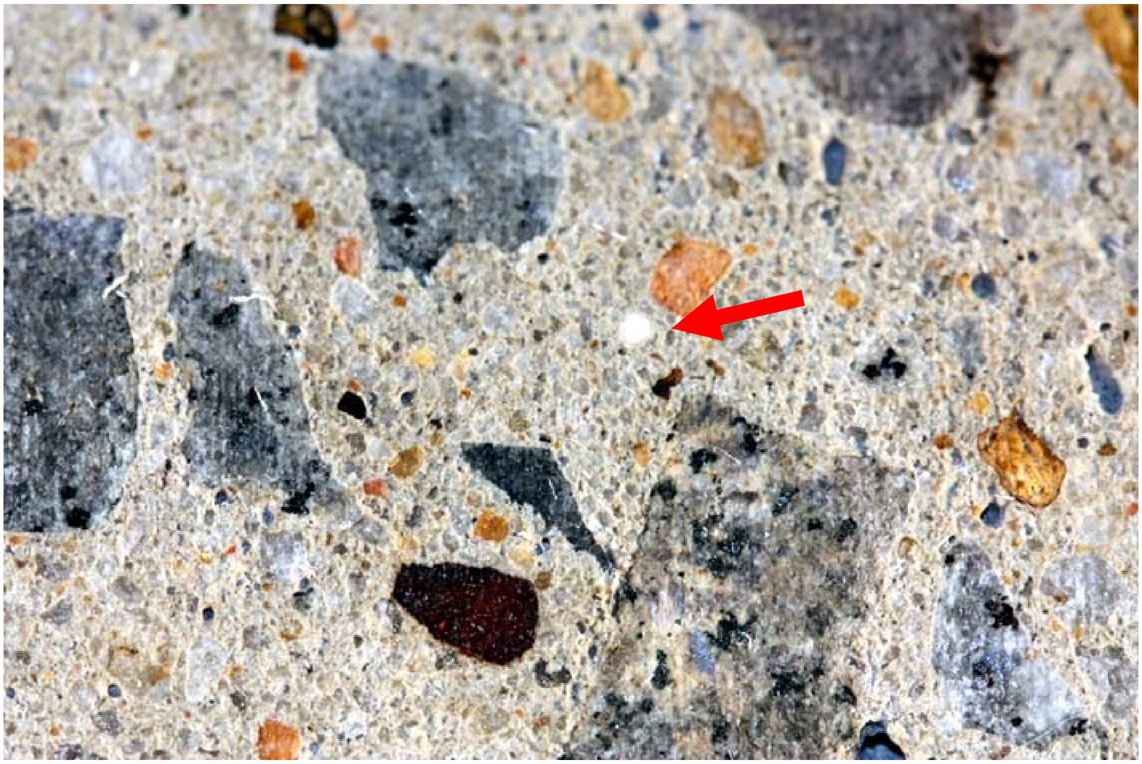


Figure A10: Details on core Ark-5. A: reaction rim and cracks with alkali-silica reaction product in a reacted particle of the fine aggregate; B: air void filled with alkali-silica reaction product.

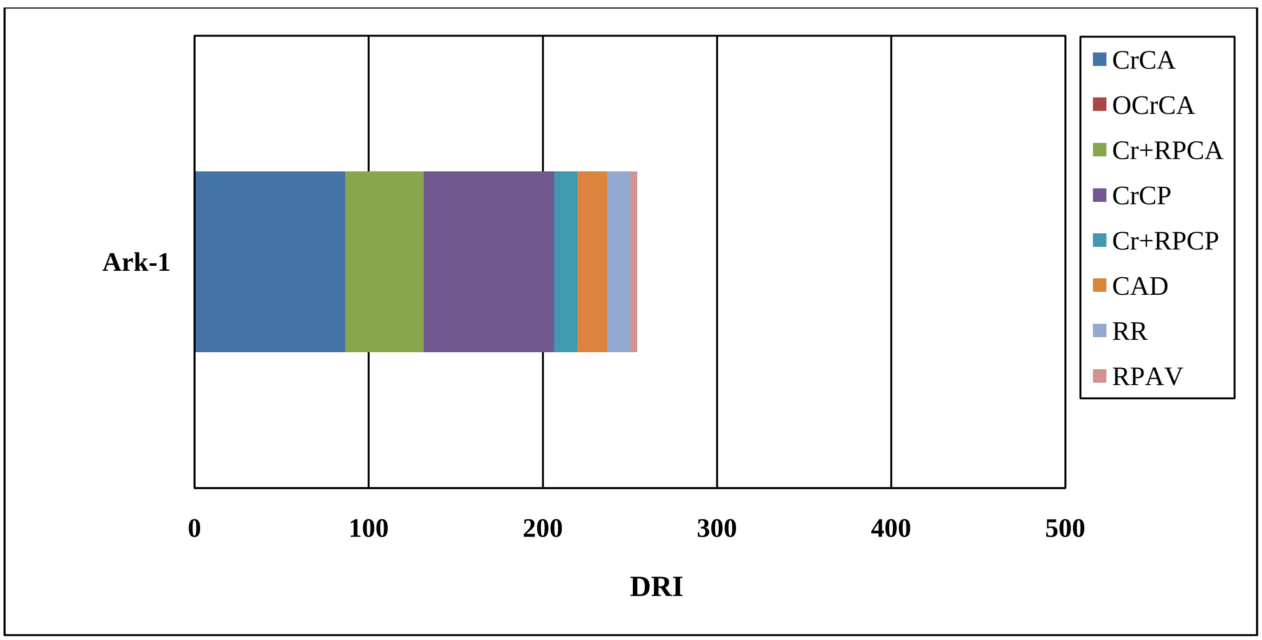
Appendix B

Photographs of the polished concrete core sections,

detailed results of the DRI and

micrographs of the petrographic symptoms of deterioration

Core: Ark-1



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	DRI
Ark-1	86	0	45	75	13	17	13	4	**254**

Figure B1: Polished core section Ark-1 and DRI results

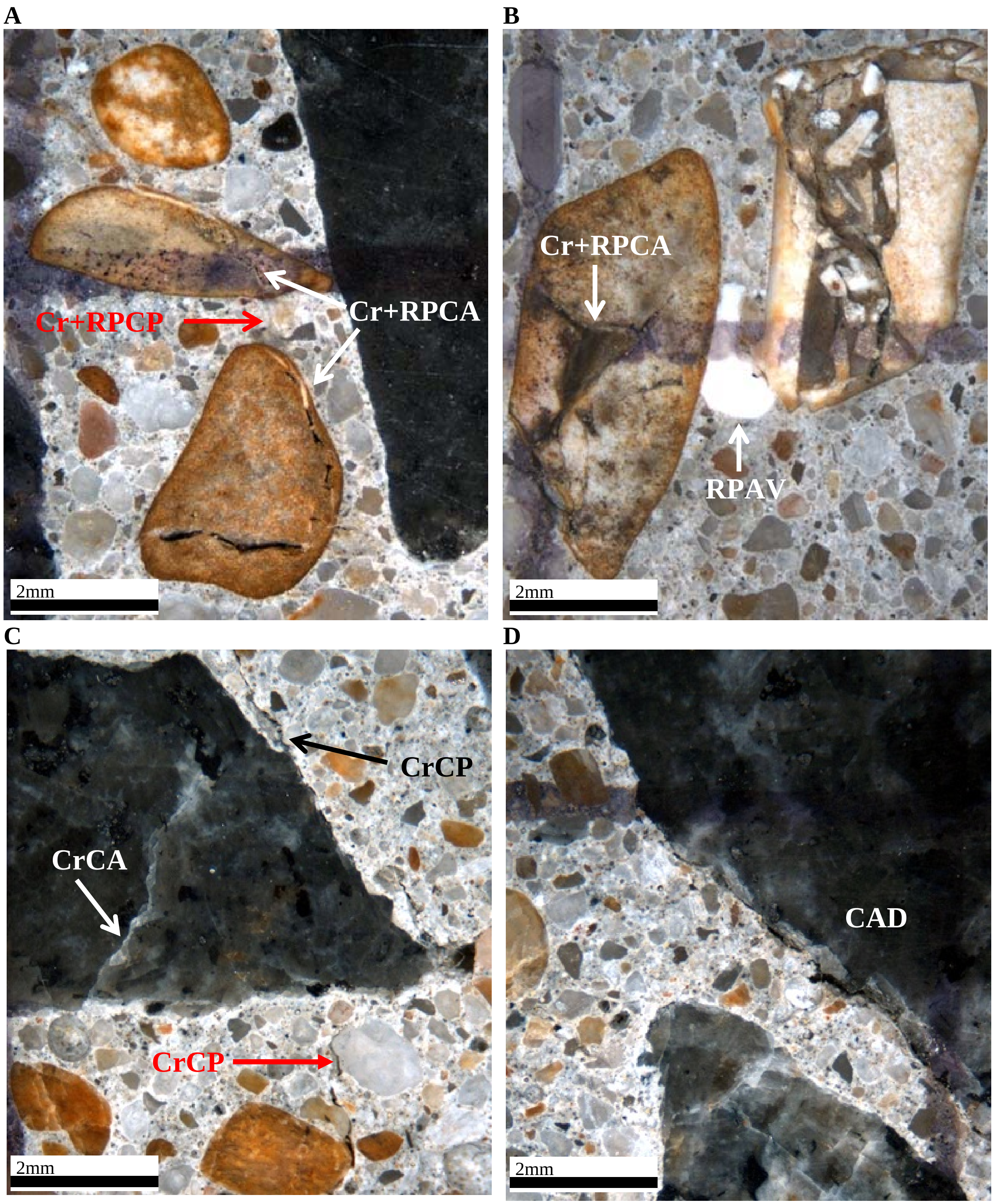
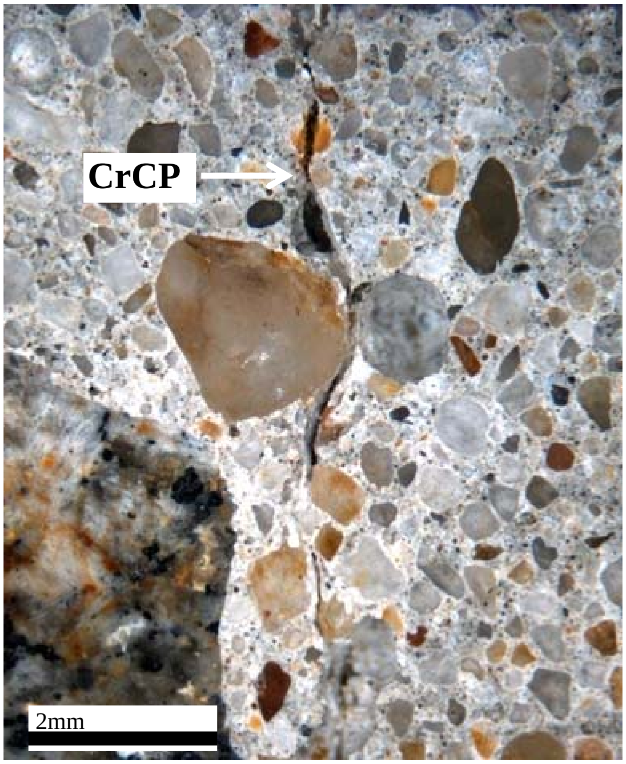


Figure B2: Micrographs showing petrographic features observed on the concrete polished section of core Ark-1. A&B: cracks with alkali-silica reaction product in the fine aggregates (Cr+RPCA) and the cement paste (Cr+RPCP), and air void lined or filled with silica gel (RPAV); cracking in the cement paste (CrCP) and in the coarse aggregate (CrCA); debonded coarse aggregate (CAD).

E



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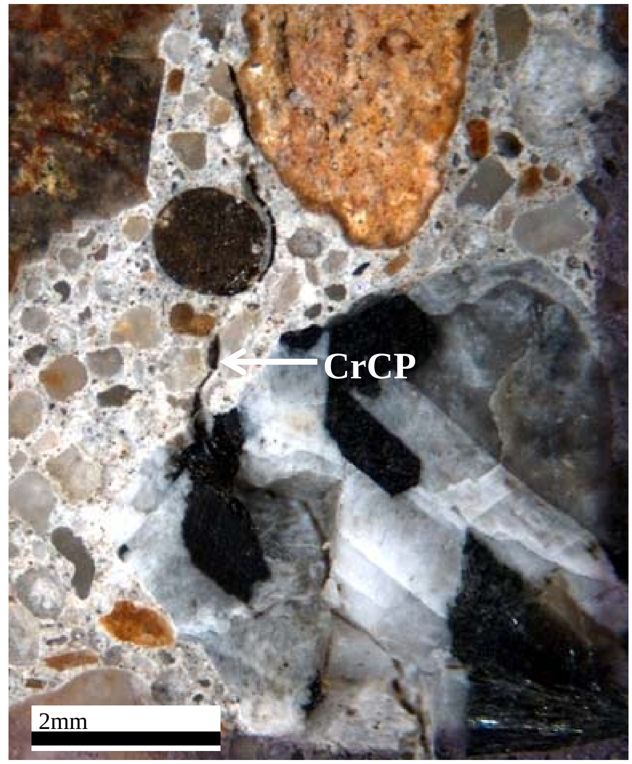
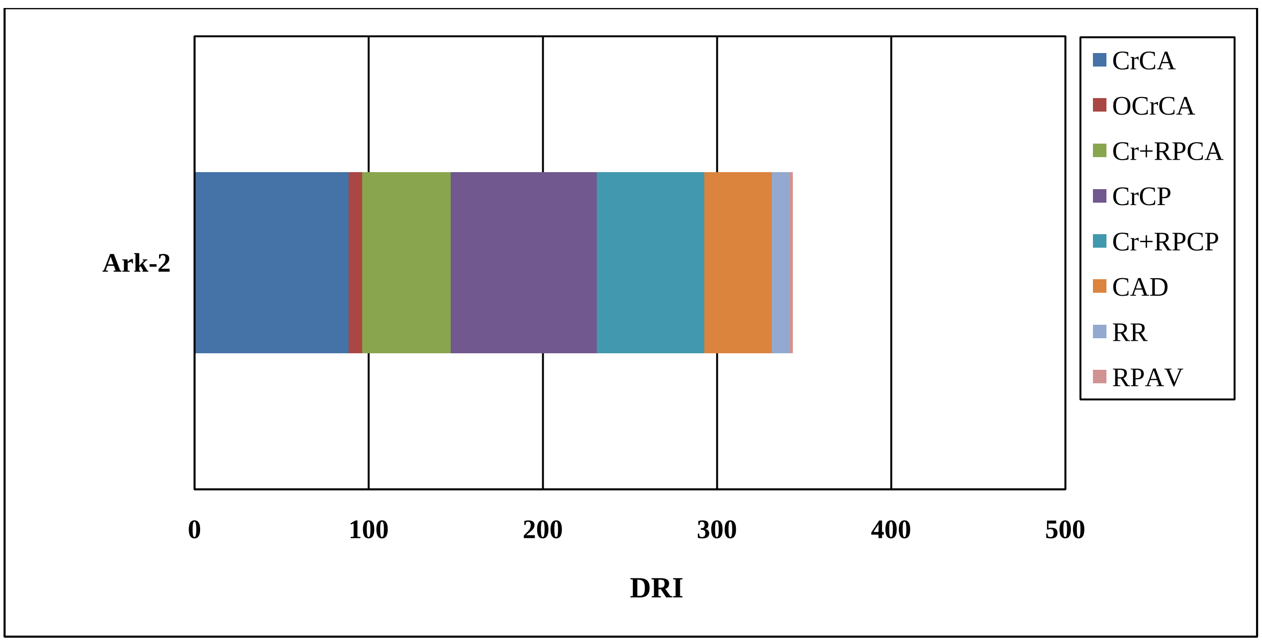


Figure B2 (cont'd): Micrographs showing petrographic features observed on concrete polished section of core Ark-1. E&F: cracking in the cement paste (CrCP).

Core: Ark-2



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	DRI
Ark-2	89	8	51	84	62	39	10	2	**344**

Figure B3: Polished core section Ark-2 and DRI results

Figure B4: Micrographs of the polished section Ark-2 [distance between vertical lines = 1 cm (0.4 in.)] showing reaction rims around a coarse particle of chert (same nature as fine aggregate particles).

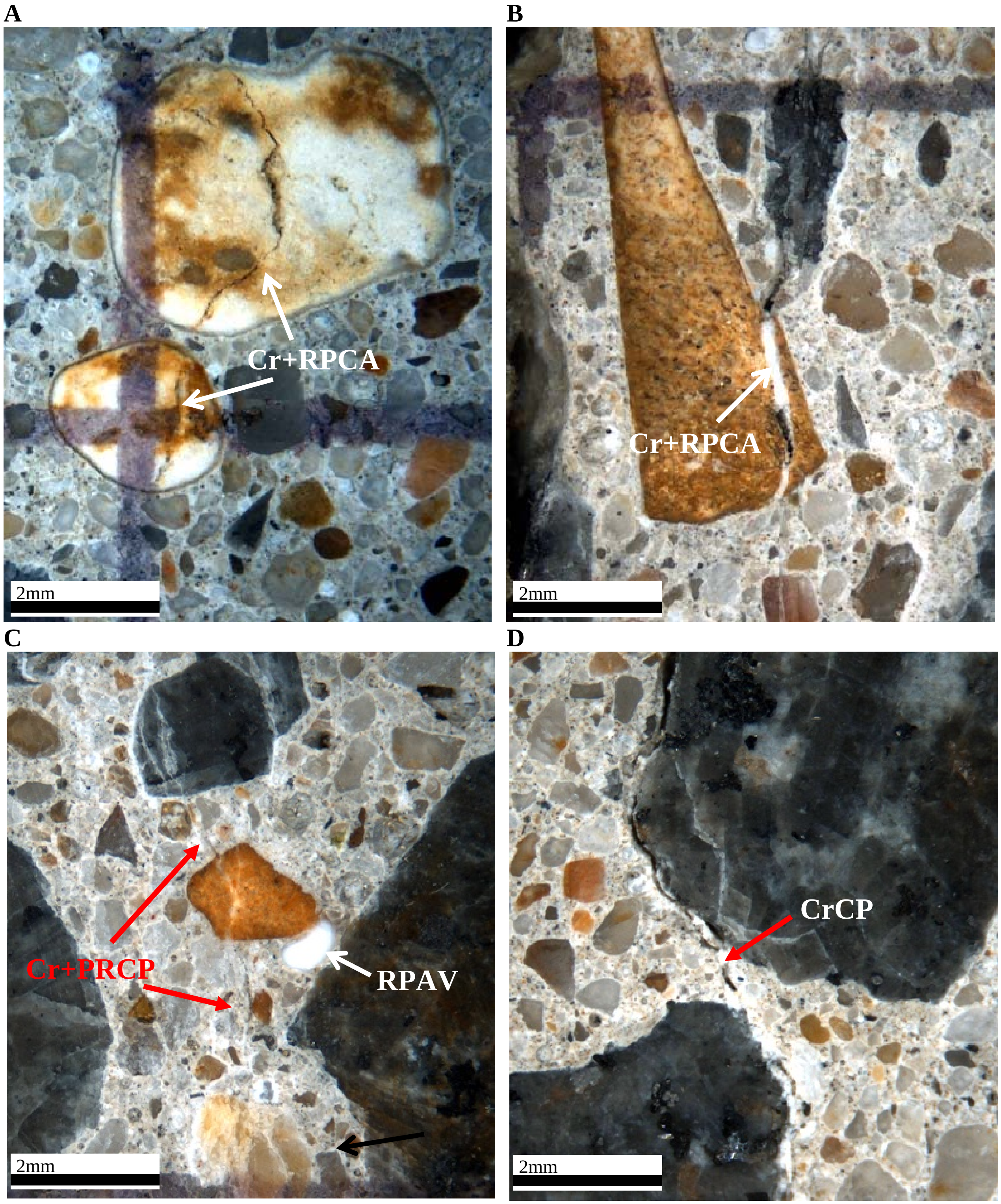


Figure B5: Micrographs showing petrographic features observed on the concrete polished section of core Ark-2. A&B: cracks with alkali-silica reaction product (Cr+RPCA) in fine aggregate particles and cement paste; C: air void lined or filled with alkali-silica reaction product; C&D: cracking in the cement paste, with (Cr+RPCP) or without (CrCP) alkali-silica reaction product.

E **F**

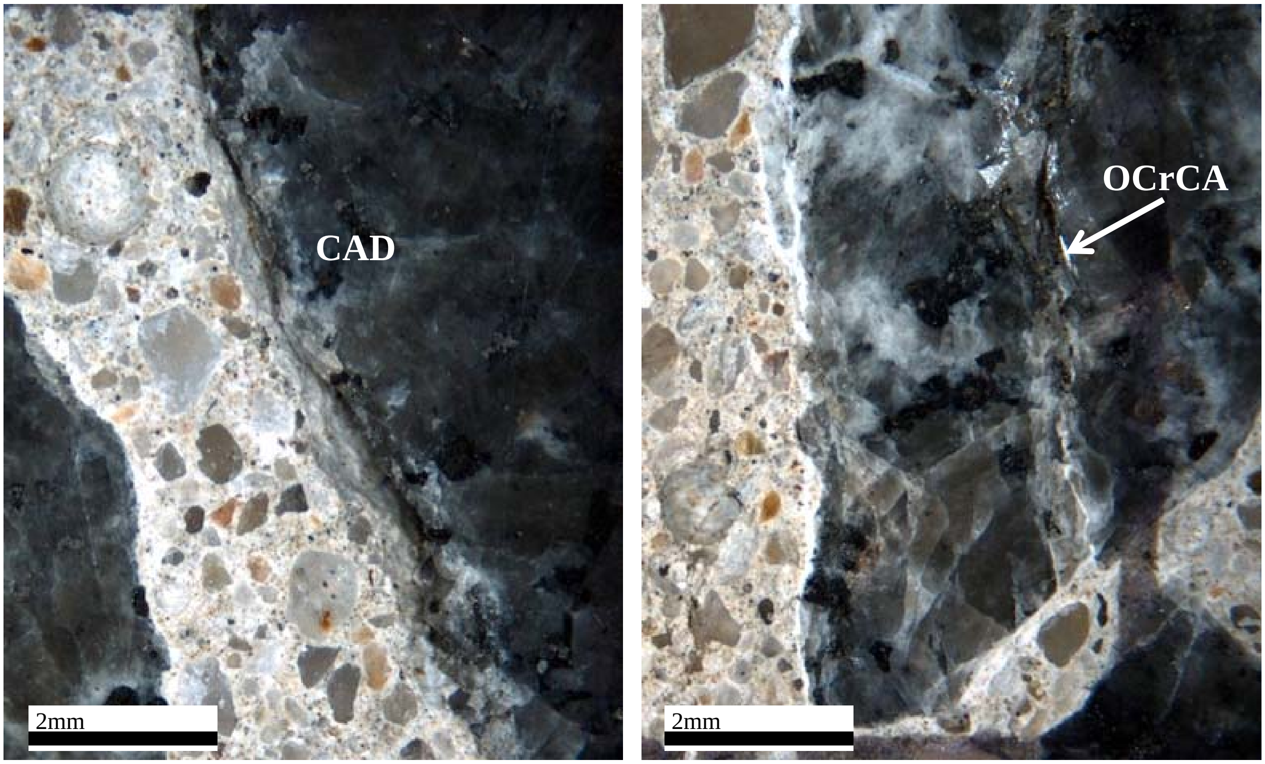
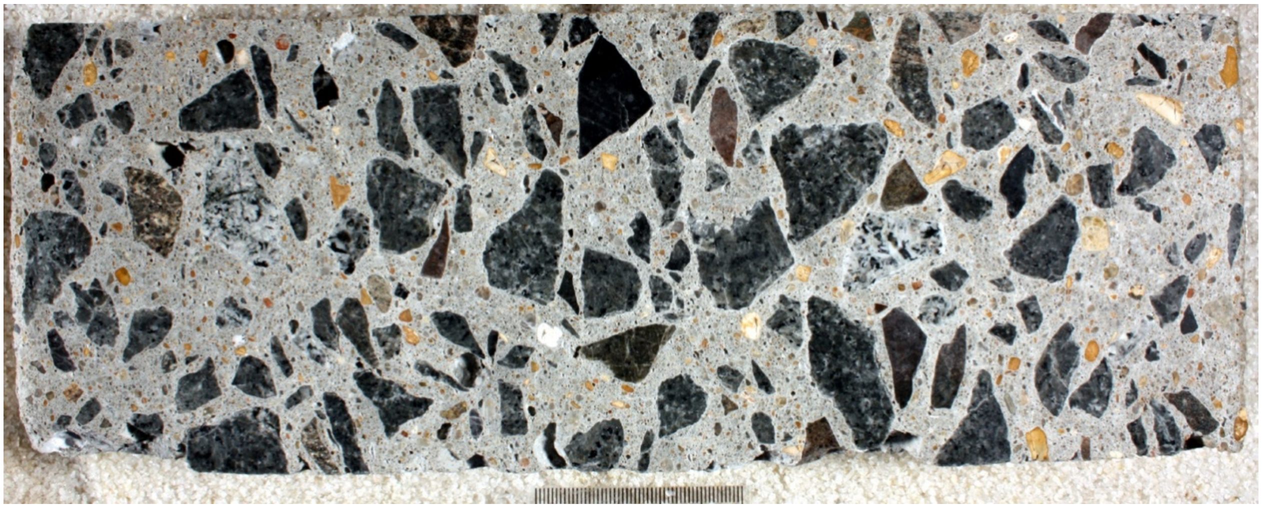
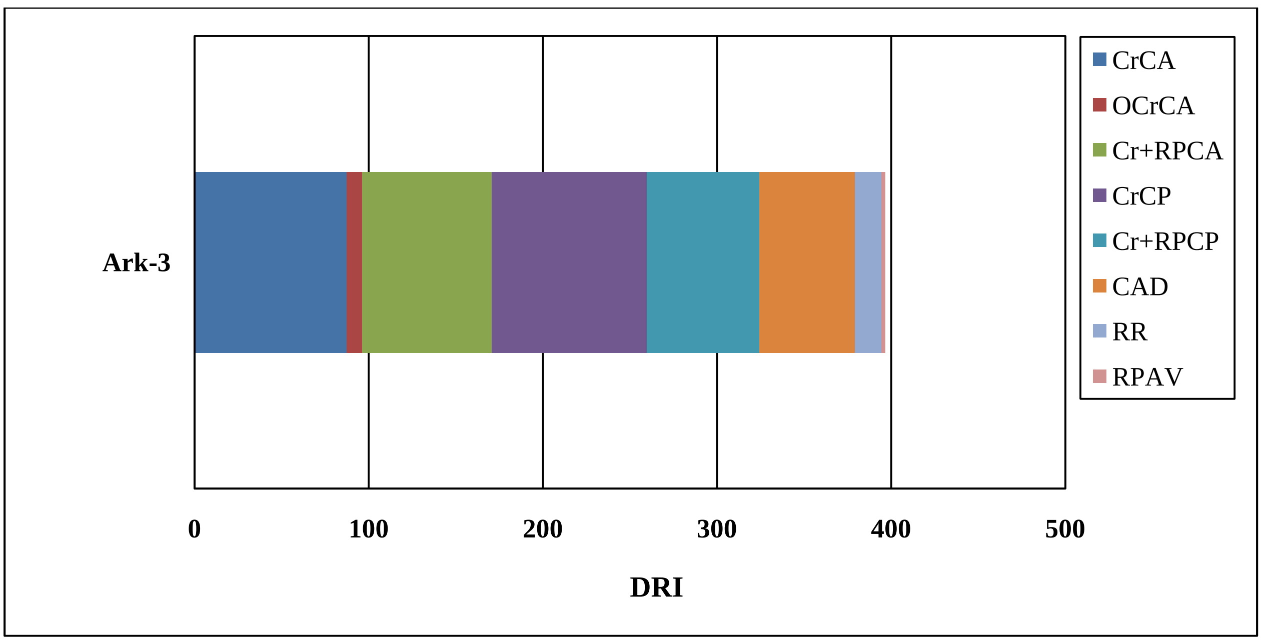


Figure B5 (cont'd): Micrographs showing petrographic features observed on the concrete polished section of core Ark-2. E: debonded coarse aggregate (CAD); open crack in a coarse aggregate particle (OCrCA).

Core: Ark-3





Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	DRI
Ark-3	87	9	75	89	65	55	15	2	**397**

Figure B6: Polished core section Ark-3 and DRI results

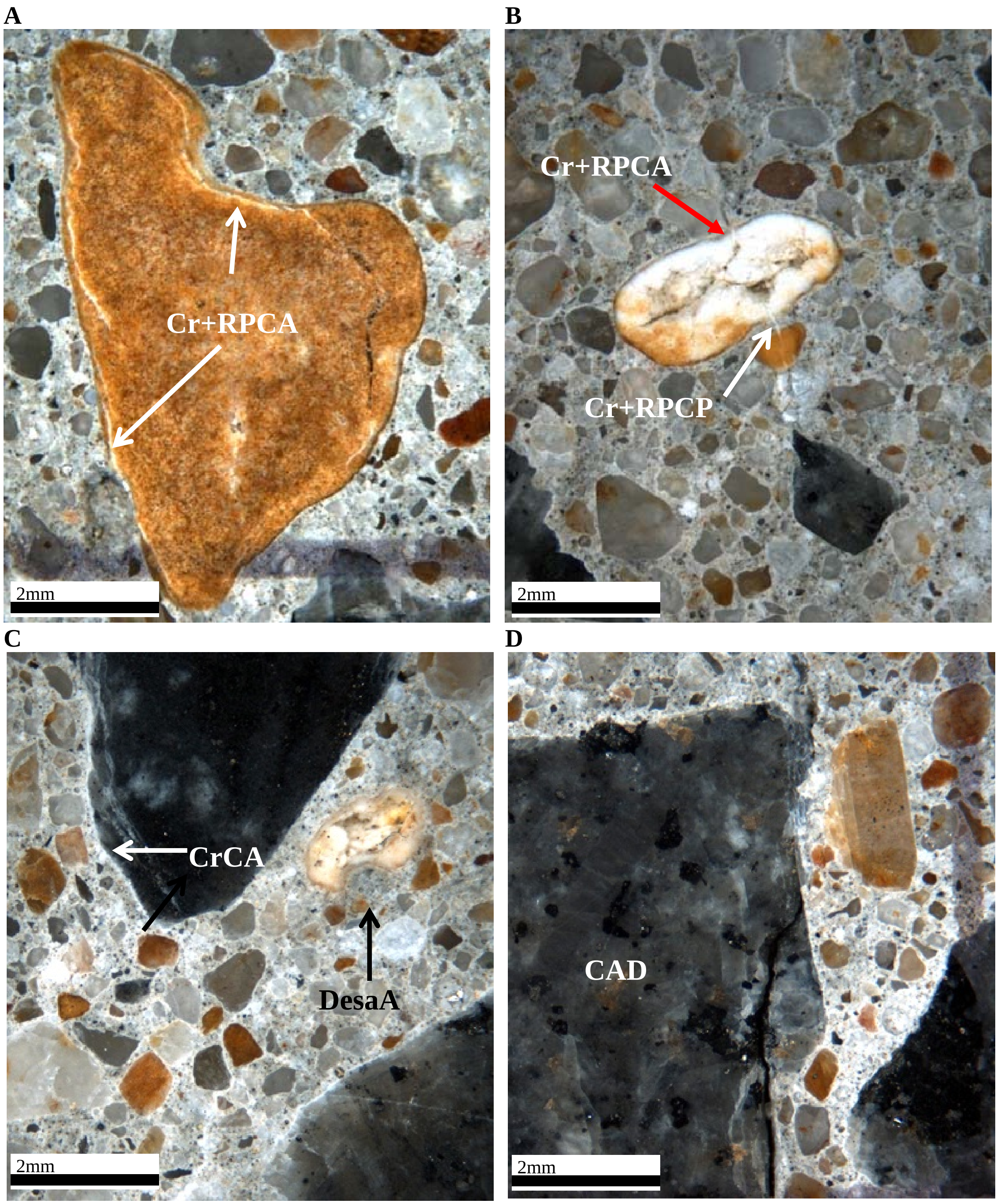
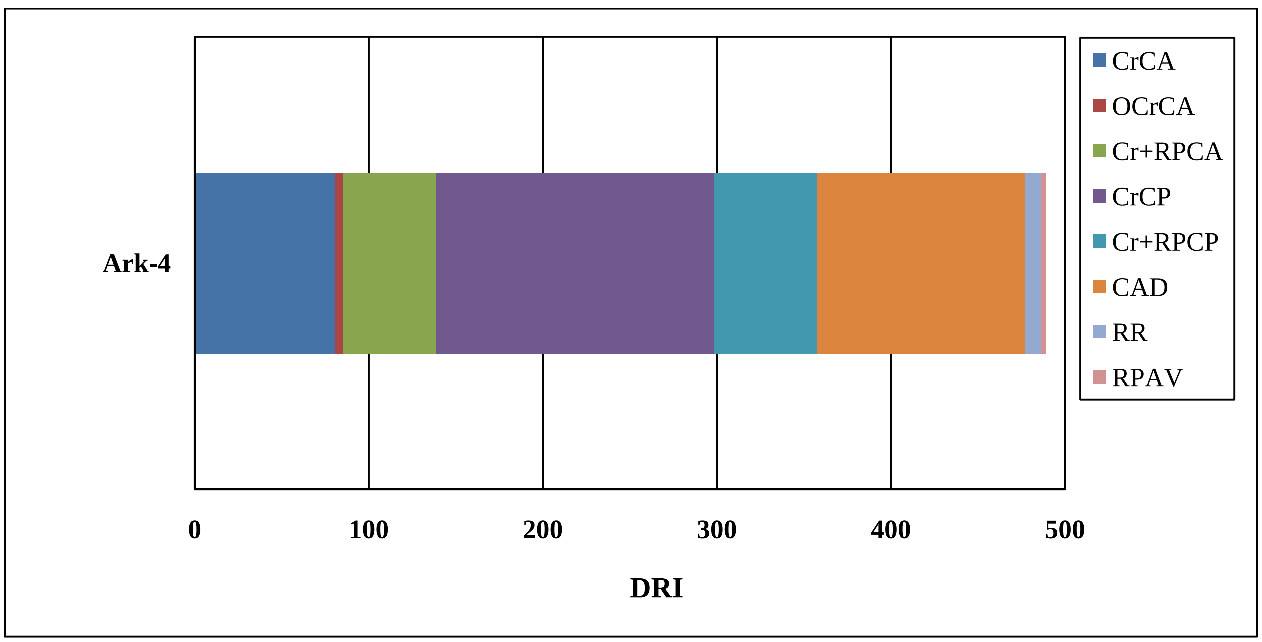


Figure B7: Micrographs showing petrographic features observed on the concrete polished section of core Ark-3. A&B: cracks with alkali-silica reaction product in the fine aggregate and the cement paste (Cr+RPCP); C: cracking in a coarse aggregate particle and a disaggregated/reacted (DCA) aggregate particle; D: debonded coarse aggregate.

Core: Ark-4



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	DRI
Ark-4	80	5	53	159	59	119	9	3	**489**

Figure B8: Polished core section Ark-4 and DRI results

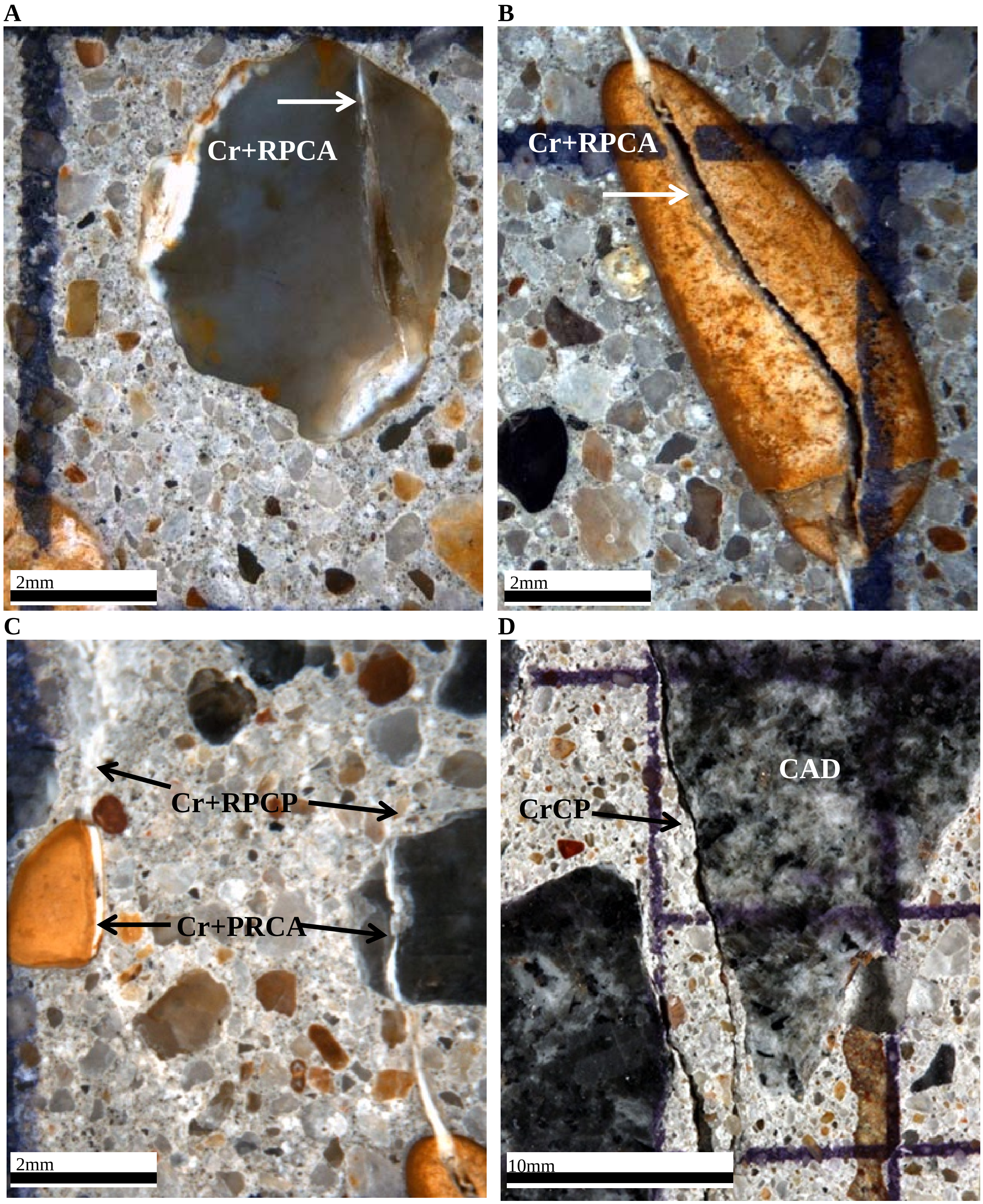


Figure B9: Micrographs showing petrographic features observed on the concrete polished section of core Ark-4. A to C: cracks with alkali-silica reaction product in the fine aggregate (Cr+RPCA) and in the cement paste (Cr+RPCP); D: cracking in the cement paste (CrCP) and a debonded coarse aggregate (CAD).

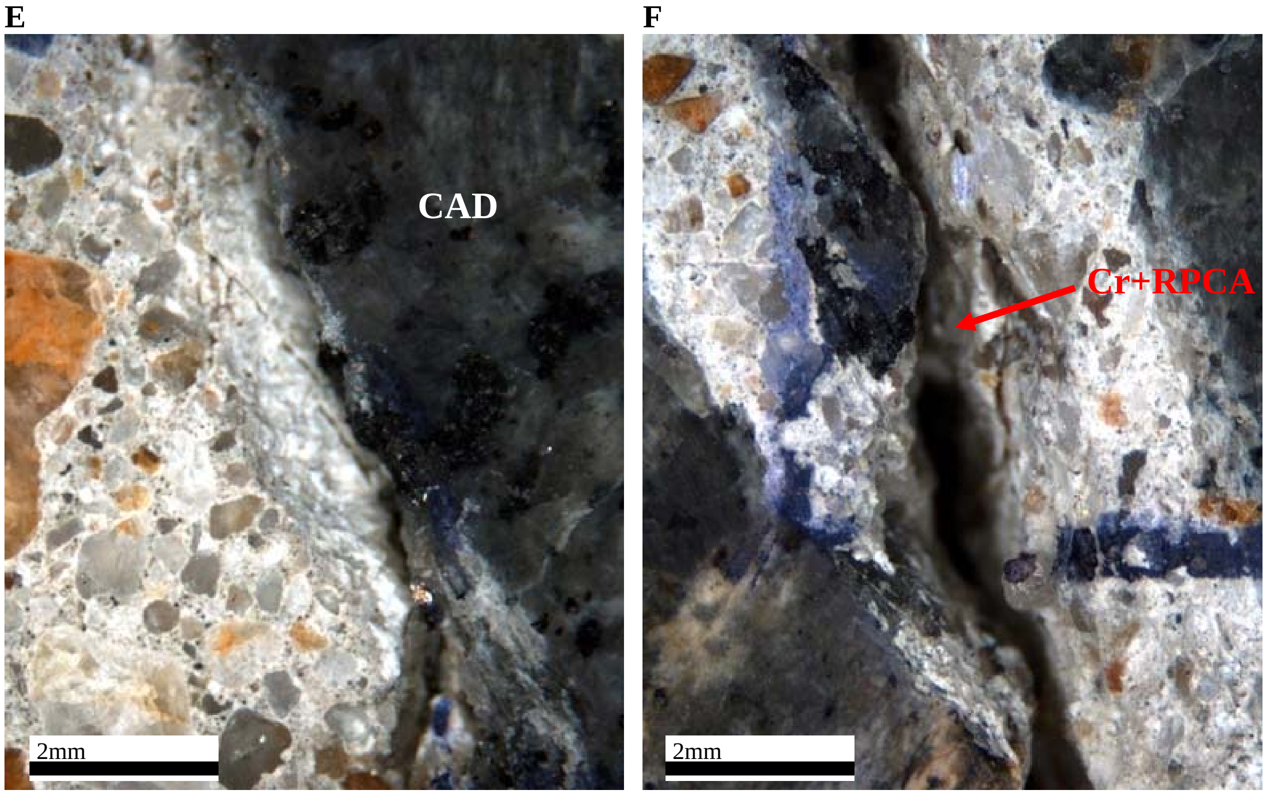
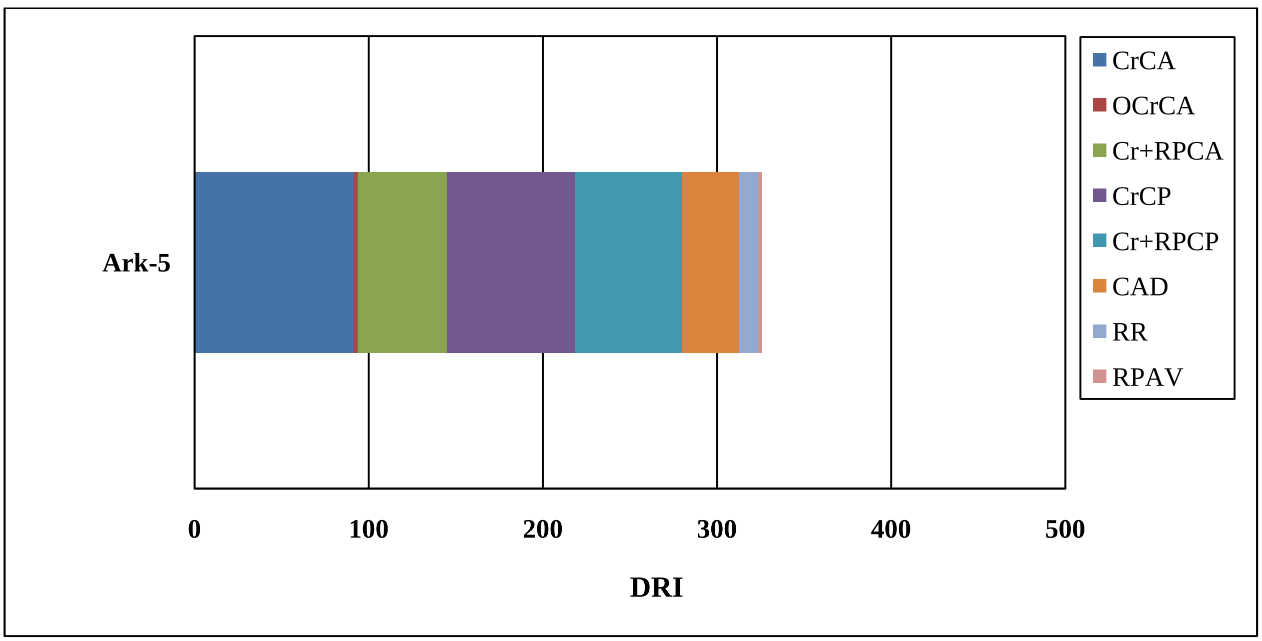


Figure B9 (cont'd): Micrographs showing petrographic features observed on the concrete polished section of core Ark-4. E: debonded coarse aggregate (CAD) and an open crack in the cement paste (CrCP).

Core: Ark-5



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	DRI
Ark-5	91	2	51	74	62	33	11	2	**326**

Figure B10: Polished core section Ark-5 and DRI results

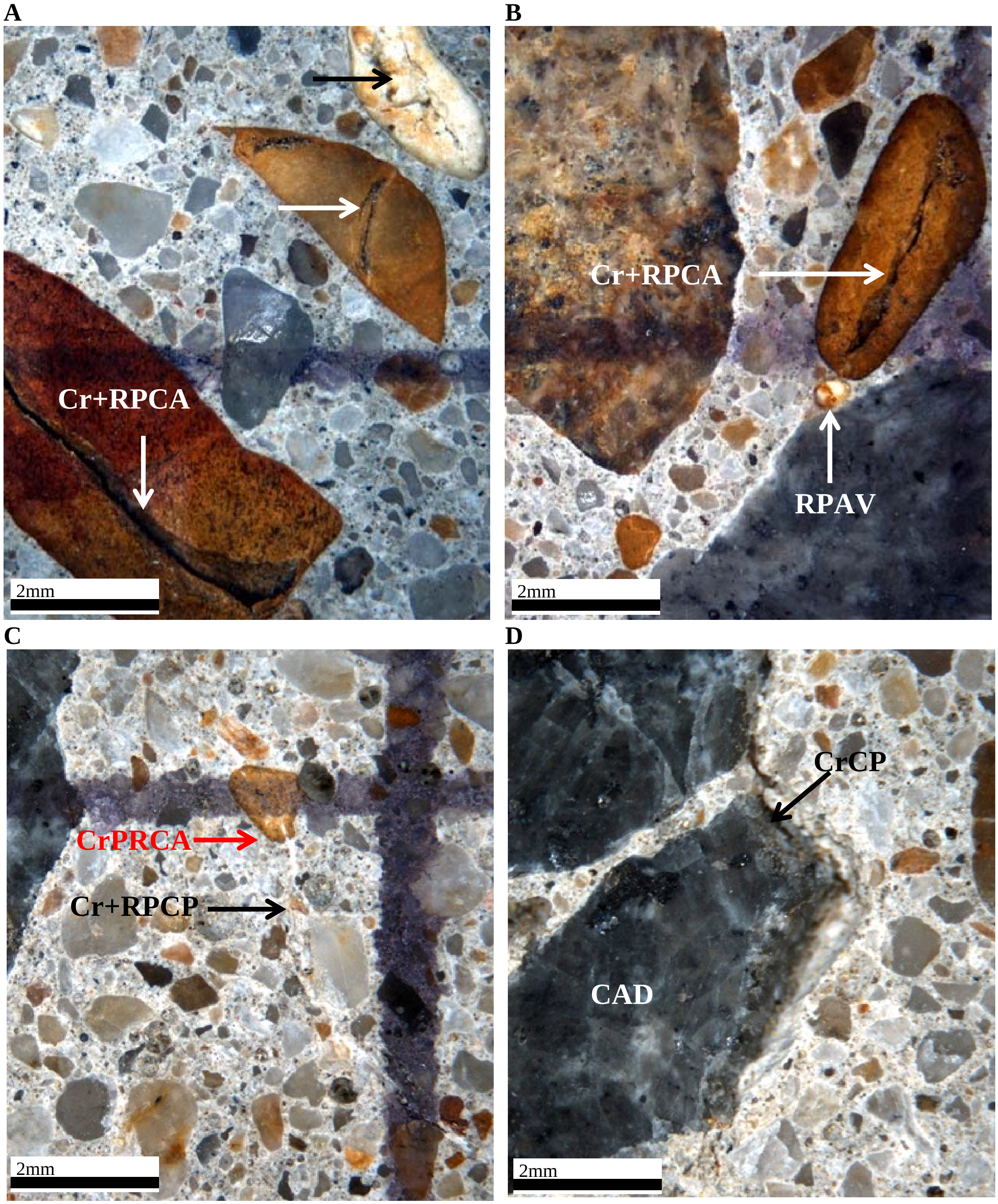


Figure B11: Micrographs showing petrographic features observed on the concrete polished section of core Ark-5. A to C: cracks with gel in the fine aggregate (Cr+RPCA) and the cement paste (Cr+RPCP); B: air void filled with silica gel (RPAV); D: cracking in the cement paste (CrCP) and a debonded coarse aggregate (CAD).

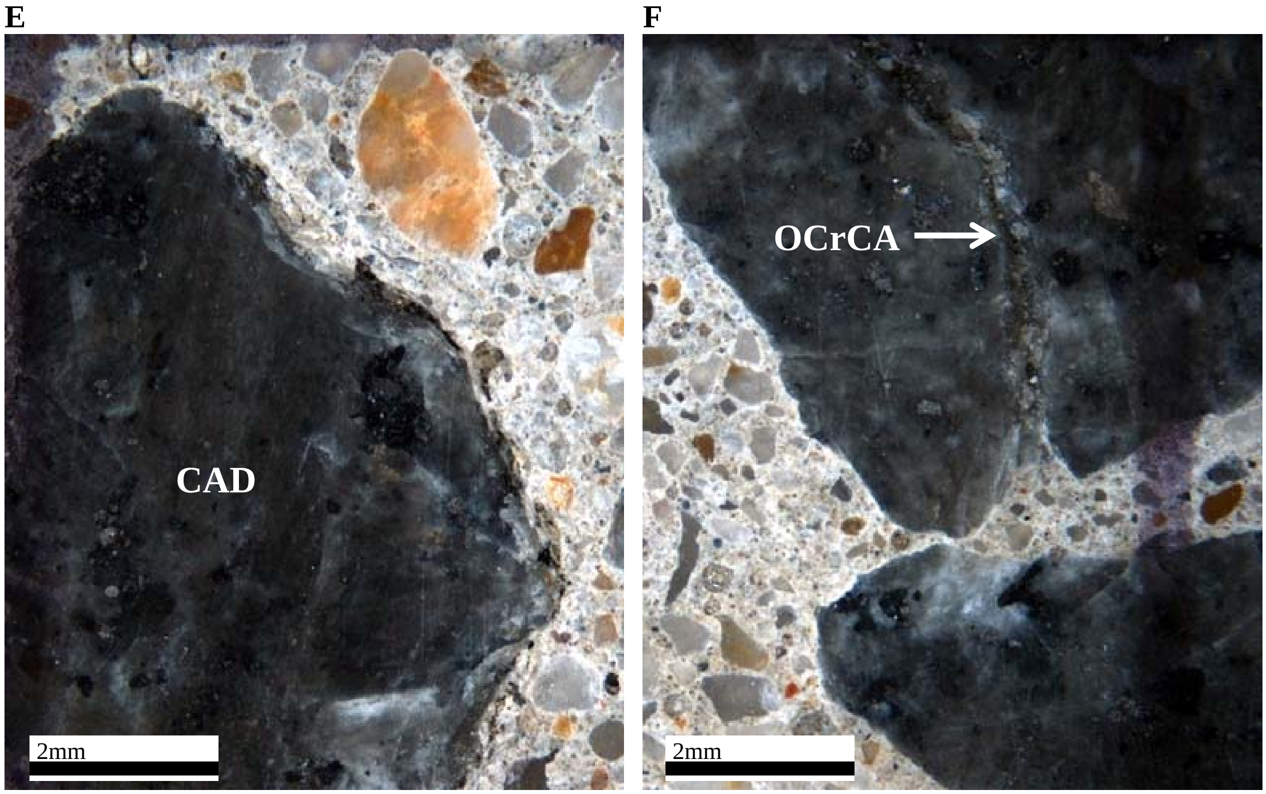


Figure B11 (cont'd): Micrographs showing petrographic features observed on the concrete polished section of core Ark-5: E: debonded coarse aggregate (CAD); F: open crack in a coarse aggregate particle (OCrCA).