Aromatic degradative pathways in Acinetobacter baylyi underlie carbon catabolite repression

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Carbon catabolite repression is an important mechanism allowing efficient carbon source utilization. In the soil bacterium Acinetobacter baylyi, this mechanism has been shown to apply to the aromatic degradative pathways for the substrates protocatechuic, p-hydroxybenzoate and vanillate. In this investigation, transcriptional fusions with the gene for luciferase in the gene clusters for the degradation of benzyll esters, anthranilate, benzoate, hydroxycinnamates and dicarboxylates (are, ant, ben, hca and dca genes) were constructed and established in the chromosome of A. baylyi. The respective strains revealed the presence of strong carbon catabolite repression at the transcriptional level. In all cases, succinate and acetate in combination had the strongest repressing effect, and pyruvate (or lactate in case of the ben and hca genes) allowed the highest expression when these carbon sources were supplied together with the respective inducer. The pattern of repression for the different cosubstrates was similar for all operons investigated and was also observed in the absence of the respective inducing compounds, indicating a mechanism that is independent of the respective specific regulators. Repression by acetate and succinate varied between 88 % for the hca genes and 99 % for the pca genes.

INTRODUCTION

To cope with environmental and metabolic changes bacteria have complex regulatory networks. In their natural environments bacteria are usually exposed to a mixture of carbon sources. To allow the cells to use rapidly metabolizable carbon sources first, a global control mechanism represses the specific induction of other degradative pathways despite the presence of their respective substrates to ensure a hierarchical use of individual carbon sources. This higher level of gene regulation is termed carbon catabolite repression (Stülke & Hillen, 1999). There is a profound understanding of the molecular mechanism in both enterobacteria and Gram-positive bacteria. In both these groups of bacteria, sugars are preferred carbon sources and the phosphotransferase system has a central function in the mechanism. In contrast, in bacteria belonging to the genera Pseudomonas and Acinetobacter, organic acids play an important role as preferred carbon sources and the understanding of the molecular mechanism is far from complete (Gerischer, 2002; Gerischer et al., 2008).

In Acinetobacter baylyi (Vaneechoutte et al., 2006), carbon catabolite repression has been described affecting the expression of the pca-qui operon, the pob operon and the van genes (Dal et al., 2002). These genes code for enzymes required for the utilization of protocatechuic (pca), p-hydroxybenzoate (pob), quinate, shikimate (qui) and vanillate (van). It could be shown that in the presence of the organic acids succinate and acetate in addition to the aromatic compounds the expression level of the pca-qui operon was repressed by at least 90 % during the growth phase. The pca genes are part of the β-ketoadipate pathway, which allows the organism to utilize a large variety of aromatic compounds (Williams & Kay, 2008). This pathway consists of two parallel branches, starting with protocatechuic (3,4-dihydroxybenzoate) or catechol (Cánovas & Stanier, 1967). The different aromatic substrates are converted to central metabolites via short funneling pathways (Fig. 1) (Harwood & Parales, 1996). The expression of the genes required for catechol and protocatechuic degradation, respectively, and that of the genes for the funneling pathways is regulated independently at the level of specific induction (Gerischer et al., 2008). Most of the genes involved in aromatic catabolism are clustered in two of five islands of catabolic genes on the genome of A. baylyi (Barbe et al., 2004).

Since a strong catabolite repression of the pca operon has been shown (Dal et al., 2002; Siehler et al., 2007) we address here the question if other operons linked with aromatic compound catabolism (are, ant, ben, hca, dca) also underlie this regulatory mechanism. To answer this question we produced transcriptional fusions between the catabolic genes and the luc gene, coding for luciferase.

Abbreviations: RLU, relative light units.
Using the detected luciferase activity we monitored the gene expression during growth on different carbon sources. We could demonstrate that all five operons underlie strong carbon catabolite repression.

**METHODS**

**Bacterial strains and growth conditions.** Strains of *Acinetobacter baylyi* (Table 1) were grown on mineral medium at 30 °C as described earlier (Trautwein & Gerischer, 2001). The carbon sources were used at the following final concentrations unless indicated otherwise: succinate, 10 mM and 30 mM (indicated in the text); pyruvate, 20 mM; lactate, 20 mM; acetate, 15 mM; succinate plus acetate, 15 mM each. For induction the following concentrations were used: p-hydroxybenzoate, 1 mM; benzoate, 1 mM; anthranilate, 1 mM; benzyl alcohol, 2 mM; p-coumarate, 1 mM; adipate, 1 mM. Benzyl alcohol, p-coumarate and adipate were dissolved in DMSO.

**Antibiotics for *A. baylyi* strains were used in the following concentrations: spectinomycin, 100 μg ml⁻¹, or ampicillin, 100 μg ml⁻¹). For growth experiments the *A. baylyi* strains with the transcriptional gene fusions were precultured on mineral medium with same carbon source as later used in the experiment except for the aromatic component.

**Plasmid and strain construction.** Standard methods were used for plasmid isolation, DNA purification, restriction endonuclease cleavage, ligation and transformation (Sambrook & Russell, 2001). To obtain the DNA region of interest from the *A. baylyi* genome a PCR using *Pfu*-DNA polymerase was performed using the primers listed in Table 2 (benA1/benA2, hcaA1/hcaA2, dcaA1/dcaA2, areA1/areA2, antA1/antA2 for the respective genes). For the construction of pAC116 the PCR fragment containing the benA,B region was cleaved with *Hin*dIII and *Kpn*I and inserted into the corresponding sites of *pUC18*. To create plasmid pAC117 the 3254 bp *hca* region PCR fragment was prepared using *Nhe*I and *Nsi*I. To insert the fragment into pUC18, the vector was cleaved by *Pst*I and *Xba*I and ligated with the PCR fragment using the compatibility between the *Pst*I/*Nsi*I and *Xba*I/*Nhe*I ends. The *dca* PCR fragment was treated with *Psh*I and *Kpn*I and cloned into pUC18 using *Hinc*II and *Kpn*I, yielding pAC118. The plasmid pAC119 was made by cloning a fragment of the *are* region digested with *Bse*BI and *Sad*I into the pUC18 *Act* and *Sad*I sites. To construct plasmid pAC123 the vector pBluescript II SK(+)
was cleaved by BamHI and EcoRV and ligated with the EcoRV/BglII-treated PCR fragment containing the ant region of A. baylyi. To construct transcriptional fusions between the catabolic genes and the gene for luciferase the luc-aad9 cassette was prepared from pFW11_luc using XhoI and Stul sites to create plasmid pAC122. In pAC117 the transcriptional fusion was placed 500 bp from the start of the hcaA gene sequence, creating a 507 bp deletion in this gene. The luc-aad9 cassette in pAC122 was introduced 73 bp from the dcaA gene start. In all cases, the orientation of the cloned fragments was verified by restriction analysis.

For the construction of A. baylyi strain ADPU92 the A. baylyi DNA containing the benA-luc transcriptional fusion was separated from the vector backbone of pAC120 using the DraI and EcoRI sites. The linear fragment was used for transformation of A. baylyi strain ADP1. A selection for spectinomycin resistance encoded byaad9 of the luc-aad9 cassette was applied to ensure the homologous recombination of A. baylyi DNA. The other A. baylyi strains containing the transcriptional fusion were made as for strain ADPU92 except for the restriction sites used to remove the insert from the corresponding plasmids. To generate strain ADPU93, plasmid pAC121 was cleaved by BamHI and BgII; to obtain strain ADPU94 the dcaA-luc fusion was cut out from pAC122 by EcoRlI and SacI. The plasmid pAC124 was linearized by PstI and PstI and used to create strain ADPU95. ADPU96 was generated by transformation of A. baylyi with the PmlI–MluI fragment from pAC125.

PCR analysis was employed to verify the correct integration of the constructs into the corresponding location on the chromosome of A. baylyi strain ADP1. For this PCR the primer pair comprised one primer hybridizing in the luc-aad9 cassette (luc primer) and a second primer (ben3, hca3, dca3, ant3, antA1) binding in the immediate

### Table 1. Bacterial strains and plasmids used in this study

<table>
<thead>
<tr>
<th>Strain or plasmid</th>
<th>Relevant characteristics</th>
<th>Source or reference</th>
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<tbody>
<tr>
<td>A. baylyi</td>
<td></td>
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<tr>
<td>ADP1</td>
<td>Wild-type (strain BD413, ATCC 33305)</td>
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<td>Siehler et al. (2007)</td>
</tr>
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<td>ADPL92</td>
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<td>This study</td>
</tr>
<tr>
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<td>ADPL95</td>
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<td>ADPL96</td>
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<tr>
<td>DH5α</td>
<td>General cloning strain</td>
<td>Hanahan (1983)</td>
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<td>luc-aad9 cassette from pFW11_luc cloned into pUC18, with AccI and Smal</td>
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<td>luc</td>
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<tr>
<td>antA2</td>
<td>CCTGATTTGCCTTGCCATG</td>
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</table>
vicinity of the fusion on the chromosome but outside the DNA used for transformation. In all strains the expected PCR fragment could be amplified, thus confirming the desired construction.

**Transformation of A. baylyi strain ADP1.** For transformation of A. baylyi, 200 μl cell suspension of an overnight culture was transferred in fresh mineral medium supplied with 10 mM succinate and incubated for 2 h at 30 °C to allow the cells to start growing again. To 500 μl of these cells 0.1–1 μg linear DNA was added and incubated at 37 °C for 3 h or overnight. Then 100 μl volumes of the cells were spread on selective plates and incubated at 30 °C. Grown A. baylyi mutants were transferred on fresh selective plates several times to ensure a pure culture.

**PCR.** Cells from a bacterial colony diluted in water were used as chromosomal templates. The conditions using *Pfu* DNA polymerase and *Taq* DNA polymerase were 95 °C for 3 min, followed by 25–30 cycles of denaturation at 95 °C for 1 min, annealing at 53–68 °C for 1 min (depending on the primers), and extension at 72 °C for an appropriate length of time. The primers used are listed in Table 2. For working with *Pfu* DNA polymerase the extension time was doubled.

**Determination of luciferase enzyme activity.** D-Luciferin was added to a sample of A. baylyi cells taken at different times during growth. The luciferase enzyme activity was detected as described earlier (Siehler et al., 2007). The resulting light emission was measured and expressed in relative light units (RLU). The results were normalized by dividing the RLU by the respective OD<sub>600</sub> value. The data presented for each culture are taken from mid-exponential-phase cultures and are means based on samples from at least three independent cultures. Error bars indicate standard deviation.

**RESULTS**

**Construction of A. baylyi strains with transcriptional fusions between benA, hcaA, dcaA, areA or antA and the luciferase gene**

To detect the effect of catabolite repression we produced transcriptional fusions between the relevant structural gene promoter and the gene for *Photinus pyralis* luciferase. For the construction the region of interest was amplified by PCR and introduced into a cloning vector. The region of interest was amplified by PCR and introduced into a cloning vector. The construction the luciferase gene and a spectinomycin-resistance gene, was inserted into the genes benA, hcaA, dcaA, areA and antA. The plasmid backbone was separated from the gene construct and the latter was introduced into the chromosome of A. baylyi strain ADP1 via homologous recombination, using the ability for natural transformation of this organism. The newly generated strains contained one copy of the respective transcriptional fusion per cell and thus allowed the determination of gene expression. To examine the expression patterns of the respective promoters we used different carbon sources (lactate, pyruvate, succinate, acetate and a combination of succinate and acetate). The gene expression was induced by adding the specific aromatic compound to the medium. Due to the insertion of the luc cassette the formation of the respective enzyme in each pathway was prevented and further degradation of the respective metabolites was blocked. Therefore the aromatic compounds were added in low concentrations as an inducer. Their concentration was assumed to remain unchanged due to the interrupted catabolism, thus ensuring permanent induction.

**Carbon catabolite repression is observed in the ben and ant operons**

Benzoate and anthranilate are independently converted to catechol, allowing further degradation to proceed via the β-ketoadiapate pathway. The antABC genes coding for anthranilate dioxygenase (Bundy et al., 1998; Eby et al., 2001) and the benABC genes coding for benzoxaolate dioxygenase (Neidle et al., 1991) are homologous. The ben operon is regulated by BenM, a LysR family regulator able to activate transcription synergestically, responding to two effectors (benzoate and muconate) (Bundy et al., 2002; Collier et al., 1998; Ezezika et al., 2007a, b). In studies using a chromosomal antA-lacZ transcriptional fusion it could be shown that the antABC expression is induced by anthranilate, but a regulatory protein has not been identified (Bundy et al., 1998). According to these data the ben-luc and ant-luc constructs were induced by adding benzoate or anthranilate, respectively, to the medium.

The expression of the antA gene in strain ADPU96 was investigated during growth on different non-inducing carbon sources with or without the inducer anthranilate (Fig. 2). In all cases the inducing effect of anthranilate (16–58-fold) was obvious. Despite the presence of the same concentration of the inducer in all cultures, there were big differences in expression depending on the nature of the non-inducing carbon source. Growth on a combination of succinate plus acetate and inducer resulted in a repression

![Fig. 2](image)

(a) 

(b) 

**Fig. 2.** (a) ant-luc transcriptional fusion in A. baylyi strain ADPU96. (b) Luciferase activity of strain ADPU96 measured after growth with the indicated carbon sources in the presence (white bars) or absence (black bars) of 1 mM anthranilate.
by 95% as compared to pyruvate. Growth on succinate and inducer had the same repressing effect whereas lactate and acetate each had an intermediate repressing effect. Pyruvate was the carbon source allowing the highest induction.

The strain containing the benA-luc fusion was induced by adding 1 mM benzoate. Using succinate and acetate as a carbon source led to a strong decrease of ben promoter activity in comparison with the least repressing substrate (54-fold, Fig. 3). Succinate and acetate alone caused a light repression (about 2-fold). The highest induction of the ben-luc fusion was observed on lactate. Thus, the benA promoter showed a similar repression pattern to the antA promoter, with the slight difference that lactate and not pyruvate was the least repressing carbon source.

Repression of the are operon by additional carbon sources

The areA, -B, -C and -R genes, encoding enzymes which convert benzyl esters such as benzyl acetate through benzyl alcohol and benzaldehyde to benzoate, are located at one end of the ben-cat cluster (Jones et al., 1999). The are operon is regulated by areR, a XylR-like transcriptional regulator (Jones & Williams, 2001). For the areA-luc construct the luc cassette was introduced into the areA gene and the transcription was induced by benzyl alcohol. In this strain the utilization of benzyl esters, catalysed by AreA, is blocked but the conversion of benzyl alcohol through benzaldehyde to benzoate followed by conversion to catechol is enabled by AreCB, because the genes are transcribed in the order areCBA. In this case the added inducer can be used as a carbon source and was added to the medium at a higher concentration (2 mM).

Using pyruvate in mineral medium supplied with benzyl alcohol led to the highest expression levels (Fig. 4). The strongest reduction of activity was observed after simultaneous addition of succinate and acetate, or succinate alone (reduction by 96% or 98%, respectively). In summary, all three operons which funnel their substrates into the catechol branch show a transcriptional regulation which strongly depends on the nature of the carbon source(s) present in addition to the substrate inducer. In all cases succinate and acetate were the strongest repressing cosubstrates.

The hca genes are strongly repressed by acetate and succinate

The Hca enzymes catalyse the conversion of derivatives of 4-hydroxycinnamic acid (chlorogenate, ferulate, caffeate and p-coumarate) into protocatechuic acid (Smith et al., 2003) (Fig. 1). The HcaC CoA ligase initiates metabolism of all these substrates by converting the corresponding hydroxycinnamoyl-CoA thioesters. They can act as inducers and relieve the repression caused by the repressor HcaR (a MarR-like regulator). To induce expression of the hca genes, p-coumarate was used. It was added in a low concentration (1 µM) because of the known toxic effect caused by the presence of accumulated p-coumaroyl-CoA (Parke & Ornston, 2004).

Fig. 3. (a) Map of the ben operon, with the position of the luc cassette in A. baylyi strain ADPU92 indicated. (b) benA promoter activity in strain ADPU92. Luciferase activity was measured after growth with the indicated carbon sources in the presence (white bars) or absence (black bars) of 1 mM benzoate.

Fig. 4. (a) Map of the are gene region of A. baylyi strain ADPU95, showing the insertion position of the luc cassette replacing the indicated 787 bp salD-areA fragment. (b) are operon expression in strain ADPU95. The cells were grown on mineral medium containing the indicated carbon sources in the absence (black bars) or presence (white bars) of 2 mM benzyl alcohol.
A combination of succinate and acetate in the presence of p-coumarate led to a 14-fold reduced luciferase activity in comparison with lactate (Fig. 5). As in strain ADPU92 (benA-luc), lactate as a carbon source resulted in the highest hca operon expression, followed by pyruvate. Thus the hca operon undergoes a strong catabolite repression following the same pattern as observed for other operons connected to the protocatechuate branch of the pathway.

The dca genes underlie catabolite repression

The dca operon is part of the dca-pca-qui-pob-van-hca supraoperonic gene cluster involved in aromatic compound degradation (Smith et al., 2003). However, the enzymes encoded by the dca genes are required for the utilization of saturated, straight-chain dicarboxylic acids (Parke et al., 2001). The degradation appears to proceed through classic β-oxidation. The required enzymes are encoded by two divergent gene clusters, dcaECHF and dcaAKIJP. The dicarboxylic catabolic pathway and the β-ketoadipate pathway converge at the level of β-ketoadipyl-CoA but individual enzymes catalyse for each pathway (an observation that also applies to the β-ketoadipate pathway itself) (Parke et al., 2001; Young et al., 2005).

The regulator protein of the dca operon is DcaR, which belongs to the IclR family (Parke et al., 2001). For the luciferase activity assays the luc cassette was introduced into the dcaA gene. The specific gene expression was induced by adding 1 mM adipate to the medium, which was sufficient since the degradation of the inducer was prevented by the luc gene fusion. As shown in Fig. 6 the activity on succinate plus acetate with adipate decreased by 93% in comparison to the combination of pyruvate and adipate. Lactate led to a slight repression, and acetate or succinate alone to a stronger repression of dcaA expression. These observations strengthened the evidence that all operons of the dca-pca-qui-pob-van-hca cluster show in principle the same expression pattern in response to the presence of additional carbon sources.

The carbon-source-dependent expression pattern is independent of the induction status

Looking at the results from the reporter gene studies done with all five operons we find a strong common pattern. All the constructs show the strongest decrease of activity on succinate plus acetate followed by succinate and acetate alone. The highest expression was observed when lactate or pyruvate was used as a carbon source.

This pattern was observed in the presence of the respective substrate inducer as well as in its absence (black bars in Figs 2–6). Thus the differential expression on the non-inducing carbon sources investigated here is independent of the induction status, an observation that had been made earlier for the pca-qui operon (Siehler et al., 2007; Trautwein & Gerischer, 2001).

Fig. 5. (a) hca-luc transcriptional fusion in A. baylyi strain ADPU93. Insertion of the luc cassette led to a deletion of 507 bp from the hcaA gene. (b) Luciferase activity of strain ADPU93 measured after growth with the indicated carbon sources in the presence (white bars) or absence (black bars) of 1 μM p-coumarate.

Fig. 6. (a) Map of the dca operon, with the position of the luc cassette in A. baylyi strain ADPU94 indicated. Insertion of the luc cassette led to the loss of 69 bp from the dcaA gene sequence. (b) Luciferase activity of strain ADPU94. The enzyme activities were measured after growth with the indicated carbon sources in the absence (black bars) or presence (white bars) of 1 mM adipate.
DISCUSSION

Strong repression of all operons investigated

All the operons we investigated showed a strong reduction of promoter activity when the carbon source combination succinate plus acetate in addition to the specific substrate was used (at least 90%, Fig. 7). The respective genes are independent regulatory units and underlie specific regulation by different inducer metabolites and different regulatory proteins. Further, they are located in different regions of the chromosome of A. baylyi. These observations are thus in accordance with the phenotype of the global regulatory mechanism carbon catabolite repression.

Acetate is converted into acetyl-CoA (an energy-consuming step), which subsequently feeds into the glyoxylate cycle. Succinate is a metabolite of the citric acid cycle; acetyl-CoA becomes available by the action of malic enzyme forming pyruvate from malate. Both substrates are subsequently oxidized and used for the conservation of energy. Succinate and acetate (or the respective CoA esters) are also the products of the β-ketoadipate pathway, which in itself does not involve energy conservation. It thus makes sense that these compounds, when present at higher levels, lead to a repression of gene expression in the β-ketoadipate pathway. Pyruvate and lactate do not—these metabolites are just one or two steps away from acetyl-CoA (catalysed by pyruvate dehydrogenase and lactate dehydrogenase, respectively). It can be speculated that acetate and succinate are abundant substrates in the natural habitats of A. baylyi, whereas pyruvate and lactate are not, and therefore no regulatory response has been developed for the latter two. Of course, transport of the substrates into the cells is a process that may also be regulated and therefore also has to be considered. To our knowledge, the topic of expression/activity of transporters relevant for the substrates concerned in this study has not been investigated.

Operons affected by the repression in A. baylyi

Repression of catabolic enzymes forming the β-ketoadipate pathway was described about 40 years ago in Moraxella calcoacetic (Cóvaras & Stanier, 1967), an organism later renamed Acinetobacter calcoaceticus. More recent reports have documented the repression by succinate of many different genes. An A. baylyi strain with additional copies of the antABC genes carried on a plasmid lost the ability to use anthranilate as a carbon source (Bundy et al., 1998). The expression of the antABC genes in trans in A. baylyi was likely to cause the formation of a higher-than-normal level of catechol during anthranilate catabolism. Catechol probably contributed to the inhibition of growth. The strain grew, however, when succinate was provided together with anthranilate. It was proposed that succinate allows growth by reducing the expression of the antABC genes, supporting the findings presented here that succinate is a substrate causing carbon catabolite repression of the antA,B,C genes.

Further evidence for repression caused by succinate was reported by Jones & Williams (2001). Benzyl esterase activity on the aromatic compound alone was 33% higher than in the presence of succinate plus benzyl alcohol. Benzyl alcohol dehydrogenase activity was reduced by 63% when succinate was provided together with benzyl alcohol as compared to benzyl alcohol alone.

In the hca operon, a transcriptional hcaE-lacZ fusion was used to detect the promoter activity (Parke & Ornston, 2004). The detected β-galactosidase activity at the expense of succinate and p-coumarate decreased by 53% in comparison with the activity measured on p-coumarate alone. Using ferulate as substrate in the presence of succinate reduced the activity by 65%.

All these data suggested that multiple operons are repressed in the presence of succinate and an aromatic compound. Our results provide more evidence for this. In terms of quantitative expression differences it has to be kept in mind which method was used. It has been documented that measurements based on luciferase or β-galactosidase do differ with respect to induction or repression factors, which is due to the lower stability of the luciferase protein (Siehler et al., 2007).

All the operons investigated here are part of two large clusters that each encode pathways for catabolism of plant-derived carbon sources of mainly aromatic nature (are-sal-ben-cat and dca-pca-qui-pob-hca) (Young et al., 2005).

Clues to the molecular mechanism

Several lines of evidence indicate an involvement of Cytochrome o ubiquinol oxidase in catabolite repression (Dinamarca et al., 2002; Morales et al., 2006; Petruschka et al., 2004). The detected β-galactosidase activity at the expense of succinate and p-coumarate decreased by 53% in comparison with the activity measured on p-coumarate alone. Using ferulate as substrate in the presence of succinate reduced the activity by 65%.

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Clues to the molecular mechanism

Several lines of evidence indicate an involvement of Cytochrome o ubiquinol oxidase in catabolite repression (Dinamarca et al., 2002; Morales et al., 2006; Petruschka et al., 2004).
et al., 2001). Furthermore, evidence for a role of protein IIA^Ntr (PtsN) in catabolite repression of Pseudomonas putida has been presented (Cases et al., 2001). In some cases evidence has added that the specific regulator protein is the target of catabolite repression. An example is (methyl)phenol degradation in P. putida H (Müller et al., 1996) or catabolite repression of the alk genes in P. putida GPo1 via downregulation of the level of the AlkS protein (Yuste & Rojo, 2001). It should be noted that both alkane and phenol degradation pathways are encoded on a plasmid of P. putida. Furthermore, transcription requires σ^54 (RpoN)-containing (phl operon) or σ^70-containing (alk operon) RNA polymerase. Neither of these two conditions applies to the operons under catabolite repression control in A. baylyi (except for the are operon, which depends on σ^54). Nevertheless an involvement of the regulators cannot be ruled out at this point. For PcaU, the activator/repressor protein of the pca-qui operon, it has been documented that the pcaU transcript level corresponds to changes in the amount of the pca-qui transcript levels under all conditions tested. Whether the pcaU transcript level simply is affected by the same mechanism as the pca-qui transcript or is involved in causing the repression is unknown (Siehler et al., 2007).

**Crc is the best-studied known player in catabolite repression**

The first potential component of the mechanism described is the Crc (catabolite repression control) protein (MacGregor et al., 1991). Inactivation of the crc gene relieved the repression of a number of genes implicated in the metabolism of carbohydrates (Wolff et al., 1991) and nitrogenated compounds in Pseudomonas aeruginosa and P. putida (Collier et al., 1996; Hester et al., 2000a).

In the P. putida OCT plasmid alkane degradation pathway Crc participates in the repression observed when cells grow in rich medium, but it plays no role in the repression caused in mineral medium by organic acids (Yuste & Rojo, 2001). The number of genes that display an influence by Crc in their expression has been increased by proteome and RT-PCR analyses to include two of the three aromatic catabolic pathways (Morales et al., 2004).

Crc seems to be involved in post-transcriptional regulation in P. putida (Hester et al., 2000b). In recent reports it could be demonstrated that Crc can bind specifically to the translation initiation region of two mRNAs for transcriptional regulators (AlkS, BenR), suggesting that Crc modulates gene expression by hindering the access of ribosomes to the ribosome-binding site (Moreno & Rojo, 2007; Moreno et al., 2007).

A. baylyi contains a Crc homologue. Its inactivation caused withdrawal of catabolite repression upon pca-qui operon expression. In this organism a very strong increase in transcript stability was observed upon crc deletion for the pca-qui operon (U. Gerischer and others, unpublished data). This may be indicative of different activities of Crc in different organisms and/or at different genes. It will be exciting to explore Crc function with respect to the A. baylyi operons investigated here.

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