Alteration of authigenic K-feldspar in sandstones from Sweden

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Authigenic K-feldspar occurs as overgrowth on detrital microcline and, less commonly, as single euhedral crystals in interstitial spaces of arkosic sandstones of the Visingsö Group (Upper Proterozoic, southern Sweden). In the present study, it is shown that such authigenic feldspar, which is of early-diagenetic origin, is partly dissolved and/or replaced mostly by late-diagenetic albite and illite. When viewed under scanning electron microscope partly dissolved K-feldspars display minute etch pits or microvoids that have variable size and shape and have random or oriented patterns.

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Introduction

K-feldspar and albite are common authigenic minerals in sandstones. K-feldspar usually occurs as overgrowths on detrital microcline and orthoclase (see, e.g., Stablein & Dapples 1977; Waugh 1978) whereas albite occurs most commonly as secondary replacement of detrital K-feldspars and plagioclase (e.g., Boles 1982; Kaiser 1984; Land 1984; Walker 1984; Morad 1986) and overgrowths on detrital albite (see, e.g., Huggett 1984; AlDahan 1985). Although detrital feldspars have been shown by numerous studies to be subjected to diagenetic dissolution and replacement by clay minerals (e.g., Heald & Baker 1977; Walker et al. 1978; Morad 1984; Siebert et al. 1984; AlDahan & Morad 1987), similar observations on authigenic feldspars are rarely documented.

The purpose of the present study is to provide evidence of the instability of authigenic K-feldspar in arkoses of the Visingsö Group (Upper Proterozoic, southern Sweden). Petrography, diagenesis and geological setting of the Visingsö Group are given in Morad (1983, 1986). This study is mainly based on examination of ten samples, which contain $\leqslant$3 per cent by volume authigenic K-feldspar. Small chips (10–15 mm across) of each sample were coated with a thin layer of gold and examined by scanning electron microscope (SEM), using a JEOL JSM 840 instrument, equipped with a Link Energy Dispersive System (EDAX). Thirty thin sections of sandstones were also examined using a standard petrographic microscope.

Petrography and alteration features of authigenic K-feldspar

Authigenic K-feldspar showing euhedral habit occurs as overgrowths on detrital microcline grains (Fig. 1A), either with or without optical continuity with respect to the microcline core. In places, the authigenic K-feldspar occurs as overgrowths as well as fillings in microvoids, which appear oriented approximately parallel to the cleavage planes of the microcline core (Fig. 1B). The overgrowths usually partly envelop the microcline core (Fig. 2A) and may appear as a few isolated patches that are about 20–100 μm in size (Fig. 2B). A thin layer of illite commonly lies between the detrital microcline core and the authigenic K-feldspar overgrowths (Figs. 2A and 2B). In rocks cemented by kaolinite, the K-feldspar grows directly on the microcline core, i.e., there is no layer of clay mineral separating them as, apparently, is the case in illite-cemented rocks. Less commonly, authigenic K-feldspar is found as single euhedral crystals or as aggregates of few crystals in interstitial spaces of the sandstones (Fig. 3). Such crystals presumably lack microcline cores (cf. Walker et al. 1978; Ali & Turner 1982; Burley 1984).

It is observed in this study that most of the authigenic K-feldspar is characterized by etched surfaces due to dissolution. The pattern of dissolution varies from randomly distributed to aligned etch pits. The latter reflect the (010) and (001) cleavage planes of K-feldspar. The shape of the etch pits may be prismatic, triangular, rectangular, ovoidal or irregular.

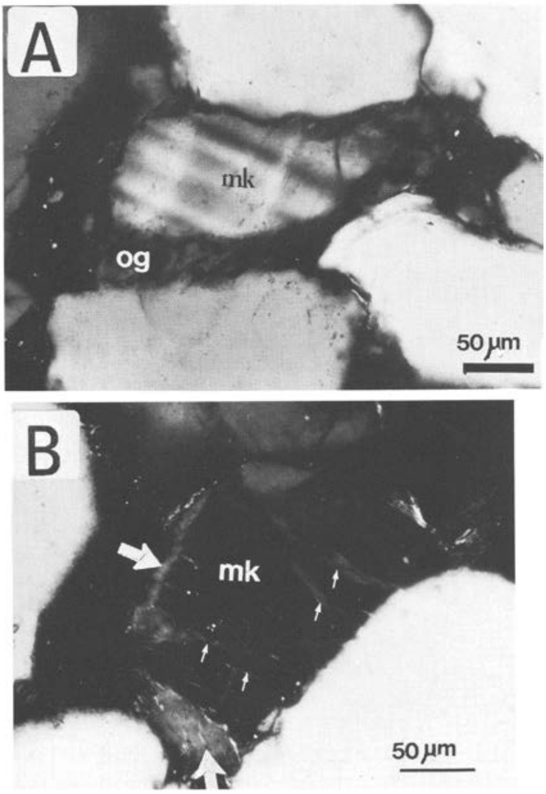

Fig. 1. (A) A detrital microcline core (mk) enveloped by secondary K-feldspar overgrowth (og). X-nicols.
(B) Authigenic K-feldspar (arrows) occurring as overgrowth on and filling fractures in a detrital microcline (mk). X-nicols.

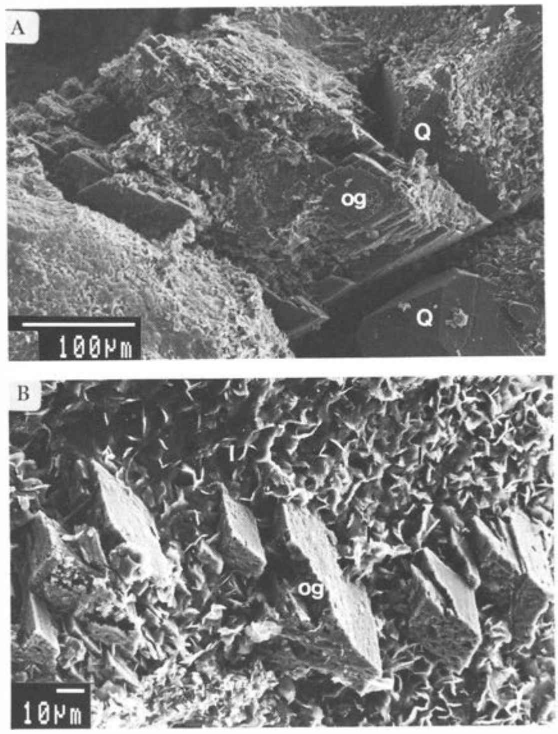

Fig. 2. (A) SEM photograph of a K-feldspar grain coated by illite (I) which in turn is enveloped by K-feldspar overgrowth (og). Q is authigenic quartz overgrowth.
(B) SEM photograph which shows patches of authigenic K-feldspar (og). I is illite coat on the K-feldspar core.

In many cases, the crystals of authigenic K-feldspar have some etch pits which occur as small scattered perforations of variable size (≤1–5 µm) and shape (Fig. 4A), as subparallel furrows (Fig. 4B), or as rectangular pits (Fig. 4C).

The dissolution of authigenic K-feldspar has in many instances resulted in the development of penetrative microcavities of different shapes. These microcavities are associated either with step-like dissolution surfaces parallel to (001) cleavage planes or with irregular dissolution of the K-feldspar surfaces (Figs. 5A and 5B). The partly dissolved authigenic K-feldspars are also commonly replaced by, mostly, illite and albite. Illite that has replaced K-feldspar occurs as randomly oriented flakes (Fig. 6A) and/or flakes arranged almost parallel (Fig. 6B), thus apparently reflecting traces of the cleavage planes of K-feldspar. Albite that has replaced authigenic K-feldspar occurs as relatively large (up to 30 µm) or as small (≤5 µm) crystals growing on and disseminated in the K-feldspar (Figs. 7A and 7B). In a few cases, albite occurs as microveins (10–40 µm wide) which cut through the authigenic K-feldspar (Fig. 7C). Illite, quartz and chlorite are minor minerals commonly associated with albitization of K-feldspar (Figs. 8A and 8B). In contrast to authigenic K-felds-

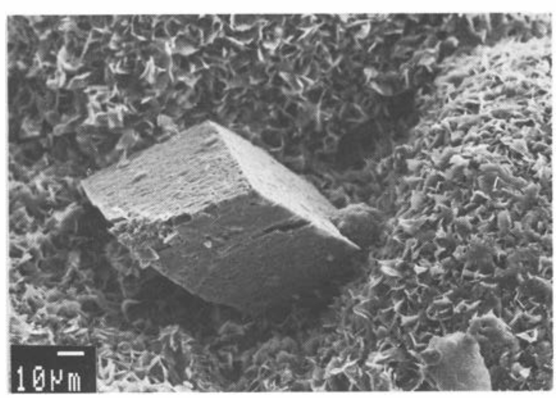

Fig. 3. SEM photograph of an interstitial euhedral K-feldspar crystal which is surrounded by illite.

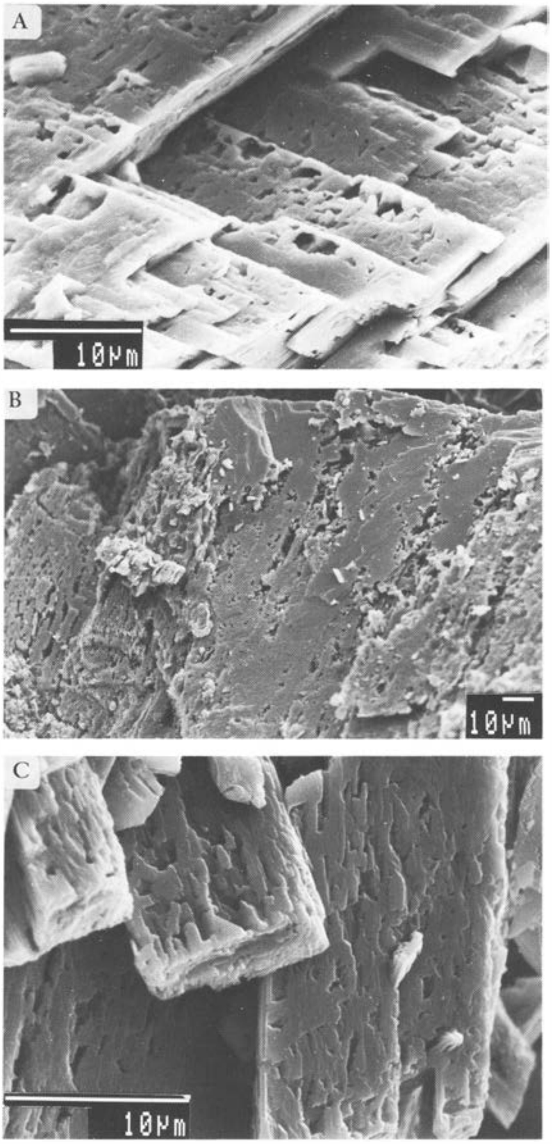

Fig. 4. SEM photographs showing dissolution patterns on K-feldspar overgrowths: (A) irregular perforations, (B) elongated, parallel grooves and (C) rectangular, oriented pits.

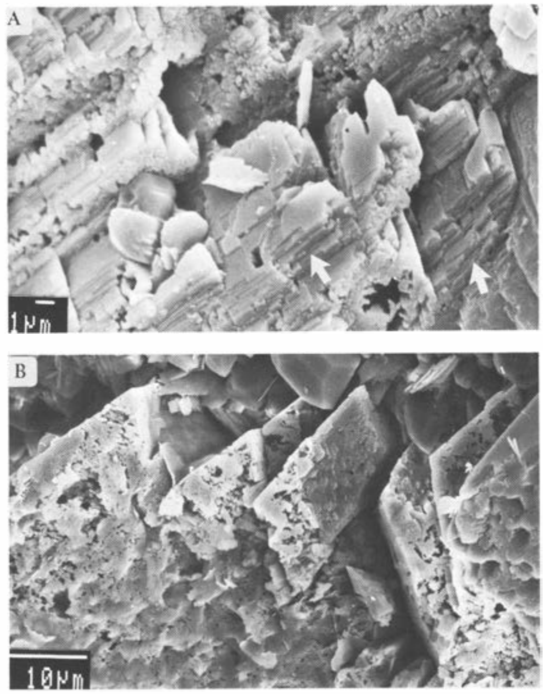

Fig. 5. (A) SEM photograph showing slight etching and development of irregular deep pits on authigenic K-feldspar. Observe the step-like dissolution feature (arrows). (B) SEM photograph showing a pervasively perforated K-feldspar overgrowth. The smooth surface of authigenic K-feldspar is almost completely destroyed.

par, the authigenic albite ($Ab_{99.7}$ $An_{0.2}$ $Or_{0.1}$), which also replaces detrital K-feldspar (see Morad, 1986) or occurs as overgrowths on detrital albite, is fresh as displayed by their very smooth surfaces (Fig. 9).

Microprobe analyses of authigenic K-feldspar overgrowths and detrital microcline cores (Table 1) commonly show almost pure end-members, $KAlSi_3O_8$. The microcline core, however, always shows a slightly higher content of Na_2O than the overgrowth. Small amounts of Ca (0.11–0.25 % CaO) and Fe (0.02–0.28 % FeO) are observed in both the overgrowth and the detrital core.

Discussion and conclusions

It is shown in this study that authigenic K-feldspar has crystallized as overgrowths around detrital microcline and, less commonly, as intergranular

Table 1. Microprobe analyses of authigenic K-feldspar (A.F.) and its detrital microcline core (D.C.).

	A.F.	D.C.	A.F.	D.C.	A.F.	D.C.
SiO_2	63.45	64.01	63.63	63.27	64.99	63.20
Al_2O_3	18.09	17.87	17.90	17.93	18.28	18.32
K_2O	16.93	16.77	16.45	16.59	15.52	16.77
Na_2O	0.84	0.92	0.67	1.98	0.32	0.38
CaO	0.12	0.22	0.22	0.13	0.25	0.11
FeO	0.07	0.05	0.28	0.02	0.09	0.13
Total	99.50	99.84	99.15	99.92	99.45	98.91

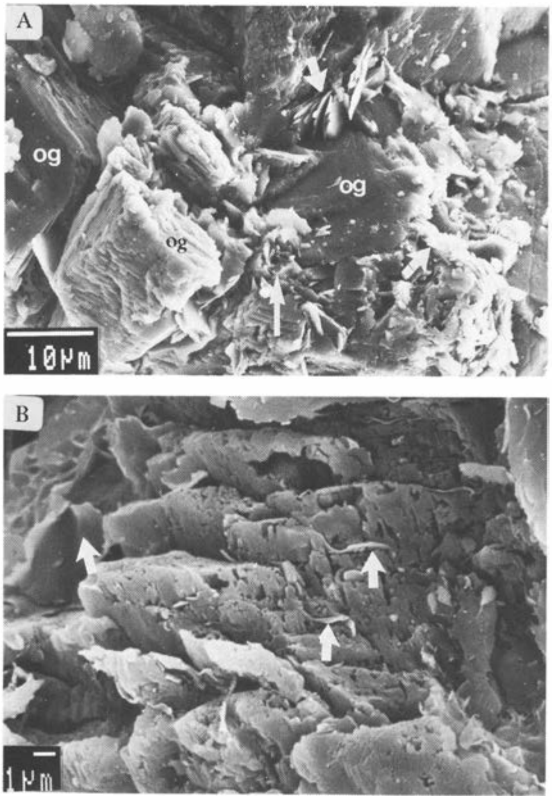

Fig. 6. (A) SEM photograph showing the replacement of K-feldspar overgrowth (og) by randomly oriented illite (arrows).
(B) SEM photograph showing parallel-oriented illite (arrows) which replaced K-feldspar overgrowth. Observe the parallel-oriented etch pits on the K-feldspar.

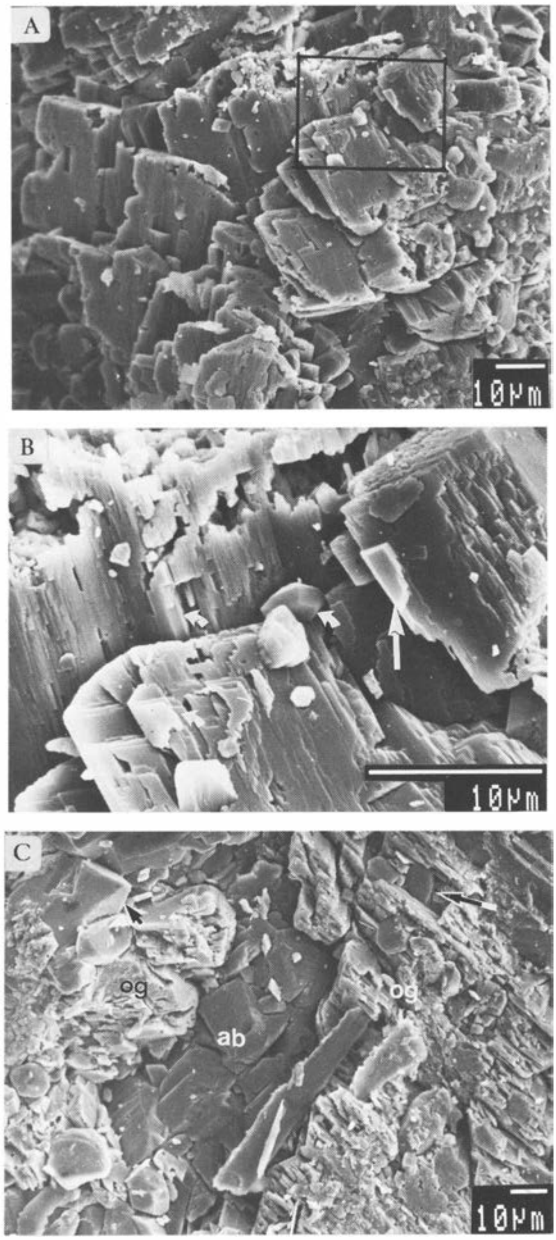

Fig. 7. (A) SEM photograph showing albitized K-feldspar overgrowth.
(B) Higher magnification of delineated area in 7 A showing the relation between albite (arrows) and K-feldspar.
(C) SEM photograph showing albite crystals (ab) which fill microfractures in K-feldspar overgrowth (og). Albite (arrows) also occurs as overgrowth on and impregnating the K-feldspar.

crystals. Evidence from petrographic examination reveals that K-feldspar was formed after precipitation of illite coats around detrital microcline. Precipitation of fine-crystalline quartz has, usually, occurred subsequently. The detrital microclines, including those around which authigenic K-feldspar has grown, are commonly pervasively dissolved. Thus, early diagenetic dissolution of detrital microcline (and to some extent biotite) could have been a major source of K, Al and Si ions necessary for the formation of illite and K-feldspar. The sequence of mineral authigenesis mentioned above, i.e., illite – K-feldspar – quartz, suggests after the precipitation of illite an increase in αH_4Si0_4 in the pore solutions (Helgeson et al. 1969). Such conditions have favoured crystallization of K-feldspar from pore solutions enriched in the ions mentioned above.

Microscopic examinations show that the authigenic K-feldspar has been subjected to dissolution and replacement by, mainly, illite and albite. This instability of authigenic K-feldspar is due to late-diagenetic changes in the chemistry of the pore solutions. Dissolution, which is the major alteration

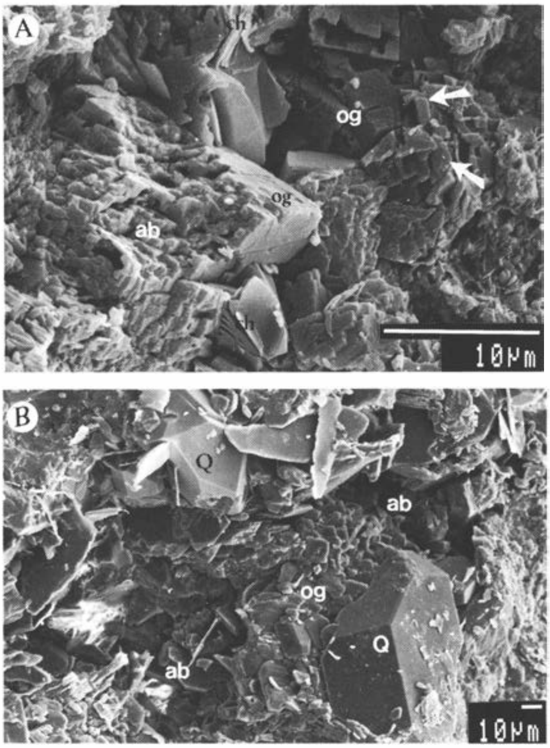

Fig. 8. (A) SEM photograph showing replacement of K-feldspar overgrowth (og) by albite (ab and arrows) and chlorite (ch).
(B) SEM photograph showing replacement of K-feldspar overgrowth (og) by quartz (Q), albite (ab) and small amounts of flaky illite.

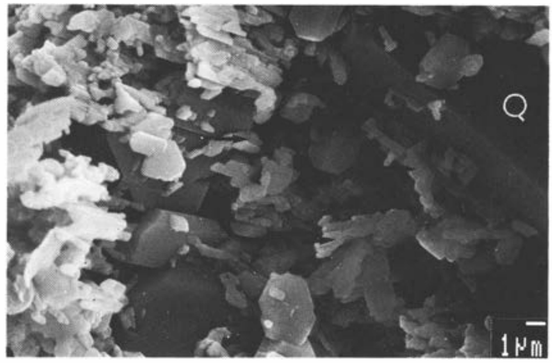

Fig. 9. SEM photograph showing albite crystals that have almost completely replaced a detrital microcline (arrows). Q is a quartz crystal.

feature observed on authigenic K-feldspar, was presumably caused by a decrease in $\alpha_{K^+}/\alpha_{H^+}$. The latter would have been caused by transformation of kaolinite and mixed-layer illite-smectite into illite (AlDahan & Morad 1986).

Replacement of the extensively etched authigenic K-feldspar by albite (Figs. 8 and 9) suggests a dissolution-precipitation process (cf. Boles 1982; Morad 1986) that has occurred late in diagenesis due to an increase in $\alpha_{Na^+}/\alpha_{K^+}$ in pore solutions and, perhaps, temperature.

The data presented here indicate that in the sandstones studied pure albite (rather than K-feldspar) was a stable authigenic feldspar phase during late diagenesis. The replacement of K-feldspar overgrowths as well as the detrital microcline by albite (Morad 1986) can be used as an argument for diagenetic (rather than detrital) origin of the albitization.

The various dissolution patterns observed on crystal faces of the authigenic K-feldspar reflect controls of cleavage planes as well as fluid and/or mineral inclusions. The dissolution patterns are relatively less complicated and less penetrative compared to those usually found on the detrital microcline (see AlDahan & Morad 1987). This is perhaps because there are additional factors that control dissolution of detrital microcline. These factors are: exsolution lamellae, twin composition planes and crystal defects (cf. Lundström 1970; Berner and Holdren 1979; Fung et al. 1980; AlDahan & Morad 1987); they are common in K-feldspars from igneous and metamorphic source rocks (cf. Velbel 1983).

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