- ¹ Yabuki, S., Gotoh, O. & Wada, A. *Biochim. biophys. Acta* 395, 258–273 (1975).
- ² Gotoh, O., Husimi, Y., Yabuki, S. & Wada, A. *Biopolymers* 15, 655–670 (1976).
- ³ Ansevin, A. T., Vizard, D. L., Brown, B. W. & McConathy, J. *Biopolymers* 15, 153–174 (1976).
- ⁴ Vizard, D. L. & Ansevin, A. T. *Biochemistry* 15, 741–750 (1976).
- ⁵ Lyubchenko, Yu. L., Frank-Kamenetskii, M. D., Vologodskii, A. V., Lazurkin, Yu. S. & Gauze, G. G., Jr *Biopolymers* 15, 1019–1036 (1976).
- ⁶ Wada, A., Tachibana, H., Gotoh, D. & Takamami, M. *Nature* 263, 439–440 (1976).
- ⁷ Lazurkin, Yu. S., Frank-Kamenetskii, M. D., & Trifonov, E. N. *Biopolymers* 9, 1253–1306 (1970).
- ⁸ Poland, D. *Biopolymers* 13, 1859–1871 (1974).

Crustal and *in situ* origin of Norwegian eclogites

KROGH¹ in a study of Norwegian eclogites concludes that all these eclogites can represent crustal rocks metamorphosed *in situ* during subduction to depths of 60–85 km. To show that eclogites are metamorphosed *in situ* demands that their conditions of formation are replicated in the adjacent amphibolite, or occasionally granulite facies, gneisses¹. In the western parts of Krogh's area eclogite equilibration conditions are $T \sim 800^\circ\text{C}$, $P \sim 23$ kbar¹. There are, however, no gneissic parageneses compatible with such conditions in which plagioclase is unstable². Thus applying geobarometric techniques^{3,4} to a pegmatite, said to be genetically related to adjacent eclogite⁵, maximum pressures are 12 kbar (ref. 3) or 13.2 kbar (ref. 4) for an assessed $T = 700^\circ\text{C}$. The occurrence of margarite in meta-anorthosites associated with eclogite⁶ gives maximum pressures of about 9 kbar⁷.

For Norwegian eclogites to be crustal demands that either their bulk chemical variations are controlled only by low- P fractionation, or that transitions from parent basalts and so on can be seen. I know of no unequivocal examples of the latter.

Krogh¹ does not seem to distinguish between the country-rock eclogites⁸ he describes and eclogites within ultramafic masses^{9,10}. He ignores critical evidence from the latter association that clinopyroxene, orthopyroxene and garnet show exsolution relationships^{9,10} which suggest high T – P conditions (1,100–1,600 $^\circ\text{C}$, 20–40 kbar) not compatible with crustal metamorphism or a subduction regime. He also ignores the description of orthopyroxene exsolving garnet from a country-rock eclogite¹¹ (recent work¹² suggests $T = 1,200$ – $1,370^\circ\text{C}$, $P = 30$ – 33 kbar).

Krogh demonstrates that there are regional variations in conditions of eclogite equilibration and that these conditions vary with time. He does not show how the eclogites reached this equilibrium. Exsolution data suggest that some eclogites at least,

formed from high- P liquids^{10,11} and are neither crustal nor *in situ*.

Paradoxically continent–continent collision processes¹ also seem a likely scenario for such rocks though dominated by deep level obduction¹² rather than subduction processes¹.

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- ¹ Krogh, E. J. *Nature* 267, 17–19 (1977).
- ² Kushiro, I. *Miner. Soc. Am. Spec. Paper* 2 179–192 (1969).
- ³ Ghent, E. D. *Am. Miner.* 69, 710–714 (1976).
- ⁴ Schmid, R. & Wood, B. J. *Contr. Miner. Petrol.* 54, 255–280 (1976).
- ⁵ Green, D. H. & Mysen, B. O. *Lithos* 5, 147–161 (1972).
- ⁶ Lappin, M. A. *Norsk geol. Tidsskr.* 46, 439–495 (1966).
- ⁷ Chatterjee, N. J. *Am. Miner.* 69, 669–709 (1976).
- ⁸ Carswell, D. A. *Norsk geol. Tidsskr.* 53, 65–78 (1973).
- ⁹ Lappin, M. A. *J. Petrol.* 15, 567–601 (1974).
- ¹⁰ Carswell, D. A. *Earth planet. Sci. Lett.* 20, 347–352 (1973).
- ¹¹ Lappin, M. A. *Miner. Mag.* 39, 313–330 (1973).
- ¹² Lappin, M. A. & Smith, D. C. *J. Petrol.* (in the press).

KROGH REPLIES—From the first sentences and the conclusion of my article¹, it should be quite clear that I am dealing with eclogites within gneisses. Low- P (<10 kbar) fractionation may, in fact, be responsible for chemical variations within eclogites². Several lines of evidence also suggest that some of the eclogites may represent meta-sediments³. Transitions from parental low- P igneous to eclogitic parageneses are in fact, described from several localities (refs 4–7 and Bryhni & Wickström personal communication).

Gneisses from Hareidland contain plagioclase–clinopyroxene symplectites along with garnet + Ksp $\pm$ bio + rutile^{2,8}, thus indicating an originally eclogitic paragenesis in which plagioclase was unstable.

Analyses of co-existing garnet + clinopyroxene pairs from granulites at Måløy show that the $K_D^{\text{FeO/MgO}}$ values here are equal to those in adjacent eclogites (L. Malinconico, personal communication). This indicates similar metamorphic conditions in these two rock types.

Margarite in meta-anorthosite associated with eclogites is suggested by Lappin⁹ to be related to local amphibolitisation of the eclogites.

The pegmatite referred to¹¹ may well be from the field and petrographic descriptions⁸ post-eclogitic. Lappin's¹¹ limitations on the maximum pressure attained by the gneisses are thus related to later, post-eclogite events.

I have demonstrated the variation in metamorphic conditions with time by studying the chemical zoning of the minerals of the eclogites.

The inferred increase in P and T from, for example, 9.6 kbar, 505 $^\circ\text{C}$ to 17.6 kbar, 720 $^\circ\text{C}$ (ref. 1, Table 1) must be regarded as a rather marked variation. I further reported relict blueschist facies mineralogy in eclogites from Sunnfjord. In these samples, the cores of both garnet and amphibole have compositions typical for blueschist facies¹⁰, while the rim compositions are more typical for eclogites within gneisses^{10,12}. Furthermore, inclusions of low- P metamorphic mineral assemblages are fairly common in the garnets of eclogites from Nordfjord^{1,5,13} and Sunnfjord¹, indicating that prograde metamorphism has produced the eclogite mineralogy.

These variations all indicate that a large increase in P and T occurred with time at individual localities, as well as from east to west across the Gneiss Region.

With regard to the exsolution phenomena in pyroxenes^{14–16}, the exsolution history is still ambiguous. The existing chemical data are not satisfactory since the chemical zoning in the exsolved phases is not investigated. These data^{14–16}, however, still tend to give equilibrium conditions that fall within the regional P – T pattern defined for the whole area¹. A more extensive discussion of the crustal and mantle derivation of Norwegian eclogites will soon be available⁵.

The evidence of mineral zoning in individual samples, and the regional variation in equilibrium conditions strongly argues that the eclogites I have studied were formed by *in situ* prograde metamorphism of crustal rocks. This does not exclude the possibility that some of the components of this terrane, such as the ultrabasic masses, may have been introduced from the mantle^{5,11,16}.

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- ¹ Krogh, E. J. *Nature* 267, 17–19 (1977).
- ² Mysen, B. O. & Heier, K. S. *Contr. Miner. Petrol.* 36, 73–94 (1972).
- ³ Bryhni, I. *Norges geol. Undersøkelse* 264, 67 (1966).
- ⁴ Griffin, W. L. & Raheim, A. *Lithos* 6, 21–40 (1973).
- ⁵ Bryhni, I., Krogh, E. J. & Griffin, W. L. *N. Jb. Miner. Abh.* 130 (in the press).
- ⁶ Gjelsvik, T. *Norsk geol. Tidsskr.* 30, 33–134 (1952).
- ⁷ Griffin, W. L. *Mem. geol. Soc. Am.* 135, 37–63 (1972).
- ⁸ Green, D. H. & Mysen, B. O. *Lithos* 5, 147–161 (1972).
- ⁹ Lappin, M. A. *Norsk geol. Tidsskr.* 46, 439–495 (1966).
- ¹⁰ Coleman, R. G., Lee, D. E., Beatty, L. B. & Brannock, W. W. *Geol. Soc. Am. Bull.* 76, 483–508 (1965).
- ¹¹ Lappin, M. A. *Nature* 269, 730 (1977).
- ¹² Mottana, A. & Edgar, A. D. *Lithos* 3, 37–49 (1969).
- ¹³ Bryhni, I. & Griffin, W. L. *Contr. Miner. Petrol.* 32, 112–125 (1971).
- ¹⁴ Carswell, D. A. *Earth planet. Sci. Lett.* 20, 347–352 (1973).
- ¹⁵ Lappin, M. A. *Miner. Mag.* 39, 313–330 (1973).
- ¹⁶ Lappin, M. A. *J. Petrol.* 15, 567–601 (1974).