†Department of Biology, Duke University, Durham, North Carolina 27708, USA
e-mail: alberts@duke.edu
‡Section of Evolution and Ecology, University of California, Davis, California 95616, USA
§Ecology and Evolutionary Biology, Princeton University, Princeton, New Jersey 08544, USA

1. Domb, L. G. & Pagel, M. *Nature* **410,** 204–206 (2001).
2. Pagel, M. *Anim. Behav.* **47,** 1333–1341 (1994).
3. Domb, L. G. *Sexual Swellings in Wild Baboons* (Papio cynocephalus anubis) *at Gombe National Park, Tanzania.* Thesis, Harvard Univ. (2000).
4. Fa, J. E. & Southwick, C. H. (eds) *Ecology and Behavior of Food-Enhanced Primate Groups* (Liss, New York, 1988).
5. Clutton-Brock, T. H. & Harvey, P. H. *J. Zool., Lond.* **183,** 1–39 (1977).
6. Packer, C. *Anim. Behav.* **27,** 1–36 (1979).
7. Alberts, S. & Altmann, J. *Am. Nat.* **145,** 279–306 (1995).
8. Altmann, J. in *Primate Males: Causes and Consequences of Variation in Group Composition* (ed. Kappeler, P. M.) 236–247 (Cambridge Univ. Press, Cambridge, 2000).
9. Nunn, C. L. *Anim. Behav.* **58,** 229–246 (1999).
10. Hamilton, W. J. in *Primate Paternalism* (ed. Taub, D. M.) 309–335 (Van Nostrand Reinhold, New York, 1984).

Domb and Pagel reply — Zinner *et al.* question our finding that the size of a female wild baboon's sexual swellings predicts her lifetime reproductive success, suggesting that we should have controlled for female height in our analyses of female fitness. But the issue is not whether a female's fitness is independent of her height, but whether males draw inferences about her fitness from her sexual swelling, and do so independently of her height. Our results indicate that they do[1,2], supporting the hypothesis that sexual swellings advertise female reproductive value.

There is no record to suggest that male baboons, or male primates of any species, prefer taller females. We have shown that males base their costly mating behaviours on the female's swelling size and not on female height, age or social rank. The amount of aggression from other males that a male must tolerate to consort a female (the key male behavioural trait[2]) is positively correlated with the size of her swelling (swelling length), statistically controlling for the effects of female height, age and rank ($r = 0.59$, $n = 13$). By comparison, males do not receive more aggression for consorting taller females ($r = 0.41$, $n = 13$; $r = -0.069$, $n = 13$, controlling for swelling size; $r = -0.25$ controlling for swelling size, female age and female family rank). Contrary to the claim by Zinner *et al.*, we did control for troop differences in these analyses[1,2], and in a way that normalized the variances, unlike their approach, which neglects this statistical assumption.

The suggestion of Zinner *et al.* that we should have analysed male interest in females' swellings when more than one female was in oestrus is based on a misinterpretation of our results. We followed an individual focal female, and not all oestrous females simultaneously. Focal females were not selected according to their swelling size. If two females were simultaneously in their maximally swollen phase, male interest towards the focal female at any given period would be influenced by the presence of the other female; if the other female's swelling was larger than that of the focal female, then male interest in the focal female could be very low.

From our results, this could be incorrectly inferred as failing to support our hypothesis. The only way to untangle such effects is to investigate all possible pairs (triples and so on) of females, following males and females simultaneously. We therefore limited our tests to those situations in which a single female was in oestrus. This procedure automatically controls for other effects and tests the hypothesis.

Zinner *et al.* repeat an earlier idea[3,4] that swellings are probabilistic signals of the timing of ovulation, which has since fallen out of favour[5–7]. Nunn has pointed out[8] that females in species with sexual swellings are attractive and mate for many more days than females in species without sexual swellings, casting further doubt on whether swellings accurately signal ovulation — in fact, they may function to confuse the timing of ovulation[9,10]. We tested the second hypothesis of Zinner *et al.* but have found no support for it[2]. This leaves the third hypothesis (ours): that swelling size signals enduring differences between females in their ability to conceive and raise offspring.

The contention of Zinner *et al.* that the reliable-indicator hypothesis is unsupported is therefore based on a misunderstanding of this hypothesis and of our results. Males endure higher costs to mate with females with larger sexual swellings[2], but not with those that are taller[1]. Females with larger sexual swellings also have higher lifetime reproductive success[2]. Baboons provide little or no paternal care, and male–male aggression over females is costly. It is important for males to direct their mating efforts towards the females of the highest fitness, and male selectivity, in turn, makes it advantageous for females to advertise their quality. The size of the sexual swelling seems to do just this.

Leah G. Domb*, Mark Pagel†
*Lawrenceville School, PO Box 6008, Lawrenceville, New Jersey 08648, USA
e-mail: ldomb@lawrenceville.org
†School of Animal and Microbial Sciences, University of Reading, Reading RG6 6AJ, UK

1. Domb, L. G. *Sexual Swellings in Wild Baboons* (Papio cynocephalus anubis) *at Gombe National Park, Tanzania.* Thesis, Harvard Univ. (2000).
2. Domb, L. G. & Pagel, M. *Nature* **410,** 204–206 (2001).
3. Hausfater, G. *Dominance and Reproduction in Baboons* (Karger, Basel, 1975).
4. Hamilton, W. J. in *Primate Paternalism* (ed. Taub, D. M.) 309–335 (Van Nostrand Reinhold, New York, 1984).
5. Thompson, J. *et al. Biol. Reprod.* **46,** 879–884 (1992).
6. Heistermann, M., Mohle, U., Vervaecke, H., van Elsacker, L. & Hodges, J. *Biol. Reprod.* **55,** 844–853 (1996).
7. Whitten, P. & Russell, E. *Am. J. Primatol.* **40,** 67–82 (1996).
8. Nunn, C. L. *Anim. Behav.* **58,** 229–246 (1999).
9. Boesch, C. & Boesch-Achermann, H. *The Chimpanzees of the Tai Forest: Behavioral Ecology and Evolution* (Oxford Univ. Press, New York, 2000).
10. Wrangham, R. in *Behavioral Diversity in Chimpanzees and Bonobos* (eds Boesch, C., Hohmann, G. & Marchant, L.) (Cambridge Univ. Press, Cambridge, 2002).

COMMUNICATIONS ARISING

Magnetic properties

Parasitic ferromagnetism in a hexaboride?

Surprisingly for a compound with no magnetic element, Young *et al.*[1] have observed ferromagnetism in calcium hexaboride (CaB_6) doped with lanthanum (La) — the system has a ferromagnetic Curie temperature as high as 600 K, which is comparable to that of transition-metal ferromagnets such as iron (Fe). Here we show that high-temperature ferromagnetism in this CaB_6 system is not intrinsic but that it is instead due to alien phases of iron and boride.

Our CaB_6 and LaB_6 samples were synthesized in a solid-state reaction[2] using three types of crucible (BN, ZrO_2 and MgO). We used an acid cleaning procedure to remove magnetic ions, such as iron, from each sample. Samples were immersed in dilute HCl and the amount of soluble iron was measured using an inductively coupled plasma instrument (Varian). The magnetization of each sample was determined before and after acid treatment by using a magnetic balance magnetometer (Cahn).

Figure 1a shows the temperature dependence of the magnetization $M(T)$ of CaB_6 synthesized using a BN crucible. Before acid treatment, a ferromagnetic feature is evident at around 600 K and 1,000 K; however, this disappears after acid treatment. This disappearance may be due either to an inherent ferromagnetism in CaB_6, with the surface state being altered by acid treatment, or to the removal from CaB_6 of ferromagnetic atoms such as iron (M. Sato *et al.*, unpublished results) by the acid cleaning procedure. As iron is detected in the acid, the second possibility is more probable.

Figure 1b shows the corresponding $M(T)$ curves measured for LaB_6. The sample that was synthesized using a BN crucible exhibits diamagnetic and temperature-independent behaviour. However, the sample synthesized using a ZrO_2 crucible shows ferromagnetic behaviour similar to that evident in Fig. 1a. The Curie temperature of LaB_6 coincides with that of CaB_6. Again, acid treatment reduces the ferromagnetic magnetization (Fig. 1b, middle curve). These results indicate that the ferromagnetism is not inherent to CaB_6 but is

due to a magnetic phase that exists in both CaB_6 and LaB_6.

We found that there was a strong correlation between ΔM and m_{Fe}, where ΔM is the difference in magnetization at around 90 K (measured before and after acid treatment) and m_{Fe} is the mass of iron dissolved in the acid. There is also a correlation between $\Delta M/m_s$ and m_{Fe}/m_s, where m_s is the sample mass (Fig. 1c). The data correspond well to the saturation magnetization, straight-line curves for the ferromagnets FeB and Fe_2B that have critical temperatures at around 598 K and 1,015 K, respectively[3]. We conclude that the high-temperature ferromagnetism observed by Young *et al.*[1] should be ascribed to these Fe–B phases.

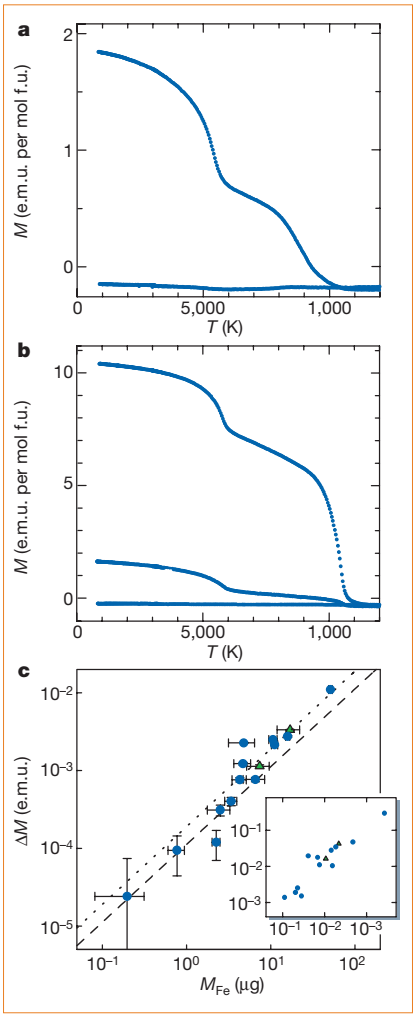

Figure 1 Magnetization of CaB_6 and LaB_6. **a,** Temperature (T) dependence of magnetization (M, in e.m.u. per mol formula unit) of CaB_6, measured at 5.1 kOe with decreasing temperature. Top and bottom curves, before and after acid treatment, respectively. **b,** Temperature dependence of magnetization of LaB_6. Top and middle curves represent the sample synthesized using ZrO_2 before and after acid treatment, respectively; bottom curve represents the sample synthesized using BN. **c,** Correlation between magnetization reduction, ΔM, and iron mass, m_{Fe}. The data are consistent with the curves indicating the saturation magnetization of FeB (dashed line) and Fe_2B (dotted line). Inset, plot of $\Delta M/m_s$ in e.m.u. per gram (m_s, sample mass) against m_{Fe}/m_s in $\mu g\ g^{-1}$. Circles, CaB_6; triangles, LaB_6.

The magnetization of CaB_6 also depends on the type of crucible used for synthesis: M measured at about 5 kilo-oersteds (kOe) at room temperature is roughly 0–2, 5–15 or 30 electromagnetic units (e.m.u.) per mol for samples synthesized using the BN, ZrO_2 or MgO crucibles, respectively. Inductively coupled plasma analysis of the used crucibles gave iron weight-concentrations, C_{Fe}, of 2–4, 17–46 and 160 parts per million for the BN, ZrO_2 and MgO crucibles, respectively. We find a correlation between M and C_{Fe}, indicating that the iron atoms moved from the crucible to the sample during synthesis.

Non-doped CaB_6 has also been claimed to exhibit ferromagnetism[2,4]. It has been suggested[5] that, as magnetic moments are confined within the sample surface of single-crystalline materials[6], there can be no intrinsic ferromagnetic moments inside the sample. It is therefore likely that the origin of the ferromagnetism in $Ca_{1-x}La_xB_6$ is the same as in CaB_6. A sintered material is useful for revealing the origin of the ferromagnetism, as it has a large surface/volume ratio compared with a single crystal. We contend that ours is a reasonable explanation for why almost all samples should exhibit the same Curie temperature, despite their experimental differences.

K. Matsubayashi, M. Maki, T. Tsuzuki, T. Nishioka, N. K. Sato

Department of Physics, Graduate School of Science, Nagoya University, Nagoya 464-8602, Japan

e-mail: kensho@edu3.phys.nagoya-u.ac.jp

1. Young, D. P. *et al. Nature* **397,** 412–414 (1999).
2. Moriwaka, T., Nishioka, T. & Sato, N. K. *J. Phys. Soc. Jpn* **70,** 341–344 (2001).
3. Chikazumi, S. *et al.* (eds) *Handbook of Magnetic Materials* (Asakawa-shoten, Tokyo, 1975).
4. Vonlanthen, P. *et al. Phys. Rev. B* **62,** 10076–10082 (2000).
5. Taniguchi, K. *et al. Phys. Rev. B* **66,** 064407-1-7 (2002).
6. Kunii, S. *J. Phys. Soc. Jpn* **69,** 3789–3791 (2000).

Young et al. *reply* — The results of Matsubayashi *et al.* on nominally stoichiometric, CaB_6 sintered powders arrive at a conclusion concerning our study[1] on ferromagnetism in this and related materials that differs in several ways from the conclusions of ongoing studies of aluminium-flux-grown single crystals (Z.F., S. Nakatsuji, F. Drymiotis, M. Bizimis, S. Yeo, J.D.T., A. Bianchi and H.R.O., unpublished results).

At issue is whether alien Fe–B phases are responsible for all of the observed ferromagnetism. Our conclusion is partly contained in ref. 2, in which it is stated that strongly interacting defects in off-stoichiometric CaB_6 (that is, comprising a few-tenths of a per cent) that carry magnetic moments are responsible for the observed ferromagnetic properties. These defects may be iron atoms scavenged during the growth of CaB_6 crystals from boron-rich flux growths. We outline experimentally based arguments (Z.F. *et al.*, unpublished results) against the suggestion of Matsubayashi *et al.* that extrinsic Fe–B phases are the source of the ferromagnetism here. Almost all studies show the surface moments to be removed in acid solution, and these will not be discussed further.

In single crystals of CaB_6 grown from molten aluminium flux (starting composition for Ca:B, 1:1–1:9) with added iron (Ca:Fe, 1:0.01–1:1), high-temperature ferromagnetism is generally observed in crystals with Ca:B ratios greater than 1:6; the magnitude of the ordered moment is 3–5 e.m.u. per mol CaB_6 for all iron concentrations in the flux (Z.F. *et al.*, unpublished results). This lack of dependence of the measured ordered moment on the iron concentration in the flux suggests that alien Fe–B phases are not the source of ferromagnetism. Also, ferromagnetic CaB_6 crystals have a metallic electrical-resistivity characteristic ($d\rho/dT > 0$; ref. 2) that is consistent with the introduction of defects into the material.

If cobalt or nickel is added to the flux in concentrations equal to those of added iron, the crystals of CaB_6 show small-moment ferromagnetism only below about 10 K (Z.F. *et al.*, unpublished results), indicating that cobalt or nickel enters CaB_6 as low-concentration defects in preference to iron, and that cobalt and nickel do not magnetically interact as strongly as iron defects.

A picture emerges in which iron is involved in the weak high-temperature ferromagnetism of CaB_6 and in which off-stoichiometric growth of CaB_6 from excess boron melting results in the scavenging of iron from the flux, giving rise to crystals of CaB_6 containing about 0.1 atomic per cent Fe. Theoretical[3] and experimental[4,5] studies of CaB_6 indicate that the stoichiometric material is a semiconductor. This suggests that the physics here shares many similarities with that of manganese-doped GaAs. It will be interesting to determine the chemistry of the iron defects, as well as how they interact so strongly and conspire to magnetic order at higher temperatures.

D. P. Young, Z. Fisk*, J. D. Thompson, H. R. Ott, S. B. Oseroff, R. G. Goodrich

**National High Magnetic Field Laboratory, Florida State University, Tallahassee, Florida 32310, and Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*

e-mail: fisk@magnet.fsu.edu

1. Young, D. P. *et al. Nature* **397,** 412–414 (1999).
2. Fisk, Z., Ott, H. R., Barzykin, V. & Gor'kov, L. P. *Physica B* **312–313,** 808–810 (2002).
3. Tromp, H. J., van Gelderen, P., Kelly, P. J., Brocks, G. & Bobbert, P. A. *Phys. Rev. Lett.* **87,** 16401/1–4 (2001).
4. Vonlanthen, P. *et al. Phys. Rev. B* **62,** 10076–10082 (2000).
5. Denlinger, J. D. *et al. Phys. Rev. Lett.* **89,** 157601/1–4 (2002).