concentration of iodine was 6.31×10^{-9} M. Since at the steady state the rates of production and consumption of iodine are balanced,

$$k_2 [S_2O_8^{2-}] [I^-] = k [I_2]_* [C_6H_8O_6]. \tag{5}$$

The left hand side of the equation has been shown to be 2.58×10^{-6} M s^{-1}. Substituting for this in equation (5)

$$2.58 \times 10^{-6} \text{ M s}^{-1} = k \times 6.31 \times 10^{-9} \text{ M} \times 5 \times 10^{-4} \text{ M}$$

where 5×10^{-4} M was the concentration of vitamin C in the reaction system. Hence

$$k = \frac{2.58 \times 10^{-6}}{6.31 \times 10^{-9} \times 5 \times 10^{-4}}$$

$$= 8.18 \times 10^5 \text{ M}^{-1} \text{ s}^{-1}.$$

From the results of similar measurements at various temperatures and from the Arrhenius plot, the energy of activation for the reaction was evaluated to be 53.1 kJ mol^{-1}. The frequency factor at 25°C was 1.82×10^{15} M^{-1} s^{-1} and the entropy of activation was -37.7 J mol^{-1} deg^{-1}.

Limits of error. It is evident in this technique that the accuracy of determination of the specific reaction rate, k, depends much upon the accurate determination of the effective concentration of iodine at the steady state evaluated from its redox potential. The other factors affecting the specific reaction rate can be controlled with greater precision. Since the redox potential due to iodine at the steady state is reproducible to ± 1 mV, the error in the determination of the effective concentration of iodine at the steady state is about $\pm 6\%$ and hence k values have an error of this magnitude.

It may be mentioned that although $S_2O_8^{2-}/SO_4^{2-}$ has a redox potential greater than that of I_2/I^-, yet, the former does not give rise to a reversible electrode[9] and therefore it is only the redox potential due to I_2/I^- which is being measured at the steady state.

In the present work the objective was to determine the specific reaction rate of a rapid reaction by applying the steady state principle and no particular efforts have been made to investigate the mechanism of the reaction.

1. Kern, D. M. H., *J. Am. Chem. Soc.*, 1954, **76**, 1011.
2. Jaenicke, W. and Hoffmann, H., *Z. Elektrochem.*, 1962, **66**, 814.
3. Ono, S., Takagi, M. and Wasa, T., *J. Am. Chem. Soc.*, 1953, **75**, 4369.
4. Varley, H., *Practical Clinical Biochemistry*, 4th edn (Indian), Arnold-Heinemann, 1975, p. 631.
5. Gowda, H. S., Mohan, B. M. and Akheel, A. S., *Talanta*, 1980, **27**, 1084.
6. Soper, S. G., *J. Phys. Chem.*, 1927, **31**, 1790.
7. Jette, E. and King, C. V., *J. Am. Chem. Soc.*, 1929, **51**, 1034, 1048.
8. Oelke, W. C. (ed.), *Laboratory Physical Chemistry*, Van Nostrand Company, Princeton, N. J., 1969, p. 333.
9. Meites, L. and Thomas, H. C., *Advanced Analytical Chemistry*, McGraw-Hill, New York, 1958, p. 29.

Forms and distribution of potassium element in salt-affected aridisol

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Two typical salt-affected soils were investigated for different forms of potassium. The available K was only 0.8–3.4% of the total soil K. The Gibb's free bonding energy indicated strong preference of K to Na in the K–Na system. The surface layer showed preference to K while the lower layers showed preference to Ca in the K–Ca system. The relative stability diagram showed that K-feldspar is the stable phase followed by mica. The sand contributed highest K to the soil followed by silt and clay. The mica increased while K-feldspars decreased with the decrease in particle size. The fluctuating water table also played a vital role in the K distribution in the soil.

POTASSIUM is found in most of the soils in varying amount depending on the weathering conditions and stage of soil formation[1]. The forms and distribution of potassium and content of potassium-bearing minerals of salt-affected soils may provide the much-needed information about the degree and stage of weathering, soil formation, potassium supplying power of soil and their management. The present study was, therefore, made to assess different forms of potassium in soil and soil fractions of typical salt-affected soils of Banaskantha district, Gujarat.

Two typical salt-affected pedons belonging to Typic Natrargids (Taluka Deodar) and Aquic Natrargids (Taluka Santalpur) were exposed for collection of horizon samples. The morphology, particle size distribution and particle fractionation have been reported elsewhere[2]. The water soluble and exchangeable K were determined by the procedure outlined by Richards[3]; the fixed K and total K in soil and soil separates by the methods of Jackson[4], and the lattice K from the difference between the total K and the sum of water soluble exchangeable and fixed K. The feldspars K and mica K in soil separates were determined after sodium pyrosulphate fusion[5]. The mean free bonding energy between K and Na was calculated according to Marshall[6].

The data in respect of forms of K, content of K in soil fractions and Gibbs free energy of exchange

between K and Na and Ca and Na are presented in Table 1. The water soluble K ranged from 0.65 to 7.62 mg/100 g. Higher concentration of water soluble K was noticed in the upper 46 cm in case of Typic Natrargids while no definite trend with depth in its distribution could be seen in case of Aquic Natrargids. A low rainfall of about 400 mm per annum could not completely leach the soluble K to lower depth in the previous case. However, a fluctuating water table resulted in an uneven distribution in the later case. The results are in line with the findings of Choudhari and Jain[7] who attributed climate to be the governing factor in profile distribution of water soluble K in soils of Rajasthan.

The exchangeable K varied from 5.1 to 26.1 mg/100 g and contributed only 0.7–3.1% of the total K present in the soil. The available K (sum of water soluble and exchangeable) was only 0.8–3.4% of the total soil K. Thus most of the potassium was in unavailable form. The content of exchangeable form was highest in the upper soil layers. This may be attributed to the low rainfall resulting in arid conditions coupled with less weathering of primary minerals[8]. Among the soil fractions, sand contributed the maximum K in the Typic Natrargids while silt and clay did so in the case of Aquic Natrargids. These results agree with those of Maheswari and Sekhon[9] who stated that K content is mainly a function of particle size distribution at various depths and partly of K content of the various size fractions.

The Gibb's free energy (ΔG°) of exchange between K and Na was calculated for depicting the tendency of the soils systems to undergo exchange. The ΔG° values ranged between -513.0 and -1874.1 J mol^{-1} at 298°K. The negative values indicated a strong preference of K$^+$ ions relative to Na$^+$. The ΔG° values for K–Ca

exchange ranged from -558.6 to $+737.7$ J mol^{-1}K^{-1}. The negative values were seen in the upper two horizons of Typic Natrargids and up to 100 cm depth in case of Aquic Natrargids. The greater negative values on the surface would indicate that the driving force for the overall process of ion exchange and K ion selectivity was greater in the surface horizon in case of Typic Natrargids and up to 100 cm depth in the Aquic Natrargids. This may be ascribed to a lower clay content in the upper horizons causing K reactions to occur more easily with less diffusional resistance[10,11]. Jardine and Sparks[12] also noticed positive ΔG° values for K–Ca exchange due to organic phase of the soil and due to particle size.

The stability diagram of phases in the K_2O–Al_2O_3–SiO_2–H_2O system at 298°K and 0.1 MPa pressure as functions of $(K^-)/(H^+)$ and (H_4SiO_4) is presented in Figure 1.

Due to arid climate very little weathering of K-feldspar is possible and therefore K-feldspar is the stable phase in these soils. K-mica is stable phase only at 46–71 cm and below 112 cm depth in case of Typic Natrargids.

A fluctuating water table coupled with a slightly lower pH and low pK (high K$^+$ activity) resulted in stability of K-feldspars, since mica is stable only at high pH and low pK[13,14].

In both the pedons increase in mica content coupled with decrease in feldspar followed the decrease in particle size. This may be due to enhanced rates of K$^+$ exchanged from interlayers by shorter diffusion paths as well as by larger specific surface[11]. Although the stability diagram (Figure 1) indicates relative K-feldspar stability in these soils, increase in mica with reduction in particle size suggest their susceptibility to weathering under suitable environment. The increase in mica with

Table 1. Forms of K, K content of soil fractions, and free bonding energy between K–Na and K–Ca.

| Depth (cm) | W.S | Forms of K mg/100 g soil | | | | K content (%) | | | | Free bonding energy J K^{-1} mol^{-1} | |
		Exch.	Fixed	Lattice	Total	Sand	Silt	Clay	Soil	K–Na	K–Ca
0–10	7.0	12.5	136.5	794.0	950	1.02	1.03	1.05	0.95	−869.1	−559.0
10–23	3.5	17.9	120.9	757.7	900	0.98	0.98	1.00	0.90	−1874.1	−80.3
23–46	2.0	15.6	117.0	715.5	850	0.93	1.03	0.91	0.85	−1021.4	28.0
46–71	0.8	14.4	113.1	691.7	820	1.07	0.95	0.91	0.82	−1429.3	41.8
71–87	0.8	10.9	113.1	735.2	860	1.31	1.03	0.81	0.86	−1021.4	211.7
87–112	0.8	9.8	105.3	554.3	670	0.93	1.03	0.86	0.67	−886.6	112.6
112–140	0.8	9.0	97.5	522.8	630	1.17	0.87	0.96	0.63	−1102.1	43.1
140–170	0.7	9.0	97.5	472.9	580	0.93	0.85	0.91	0.58	−1047.7	31.4
0–9	2.3	26.1	148.2	653.3	830	0.93	1.31	1.00	0.83	−1149.4	−38.9
9–24	3.9	20.3	140.4	585.4	750	0.84	1.08	0.95	0.75	−1070.3	−246.0
24–40	5.1	20.3	128.7	645.9	800	1.02	1.12	0.91	0.80	−1180.4	−304.6
40–55	2.3	21.8	120.9	514.9	660	1.02	0.89	0.86	0.66	−1271.2	−420.5
55–77	2.7	7.0	117.0	593.3	720	1.12	0.94	0.91	0.72	−431.8	−474.9
77–100	2.7	7.0	113.1	587.2	710	0.93	1.03	1.00	0.71	−513.0	−534.3
100–134	2.0	6.2	109.2	652.6	770	0.93	1.08	0.91	0.77	−1208.4	210.0
134–158	2.0	5.5	105.3	637.3	750	0.93	1.12	0.91	0.75	−1125.1	102.1
158–180	0.9	5.1	101.4	602.6	710	0.84	1.22	0.96	0.71	−1484.6	737.7
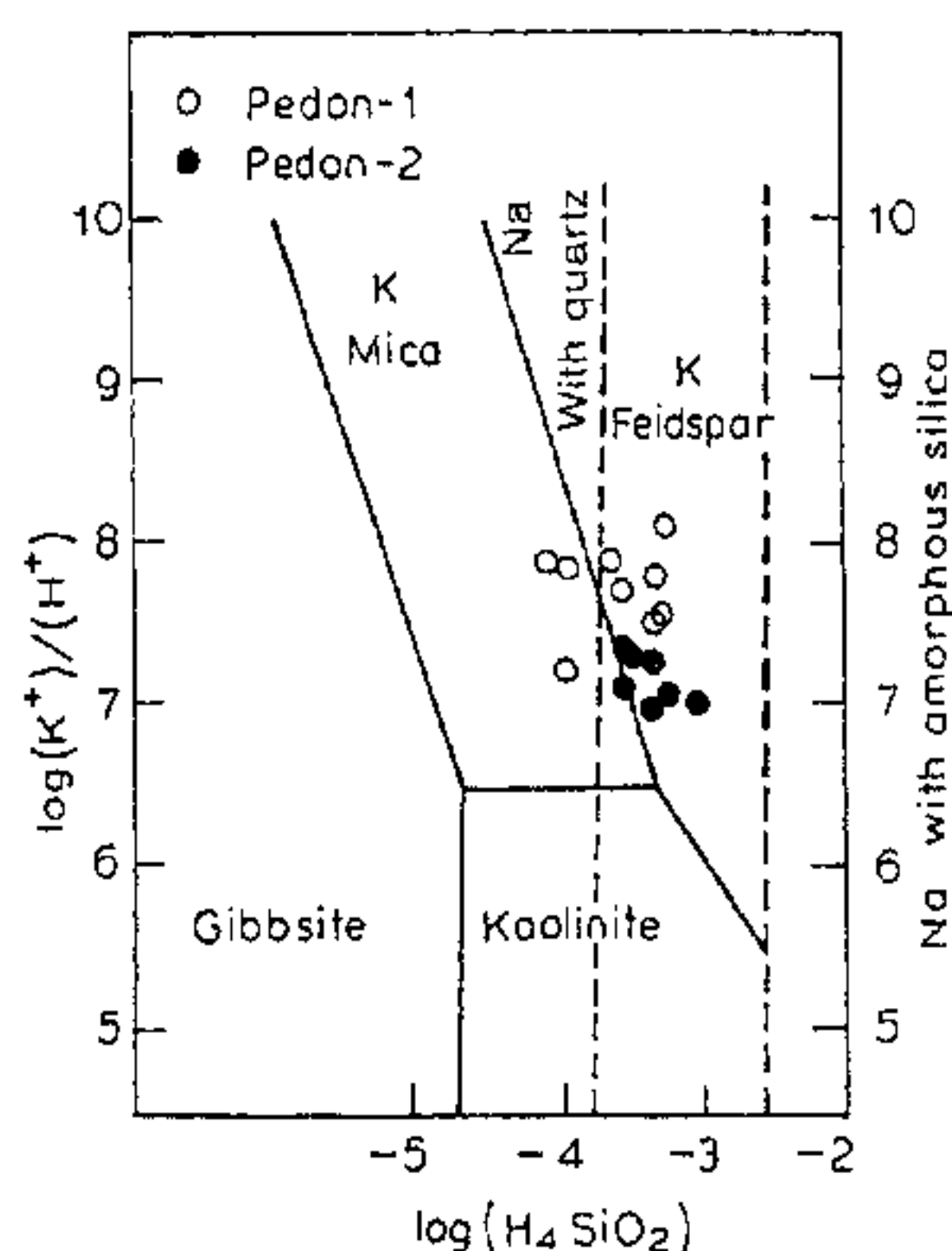
Figure 1. Stability diagram of phases in the $K_2O-Al_2O_3-SiO_2-H_2O$ system.

decrease in particle size was also reported[9] in alluvial soils of Haryana and Uttar Pradesh.

The study reveals that aridity of climate and sodicity have played a vital role in the distribution of K in the soil and different fractions.

1. Somasiri, S. and Huang, P. M., *Soil Sci. Soc. Am. Proc.*, 1971, **35**, 810.
2. Dubey, D. D., Gupta, S. and Sharma, O. P., *J. Indian Soc. Soil Sci.*, 1986, 34.
3. Richards, L. A. (ed.), *Agricultural Handbook 60*, US Dept Agriculture, Washington, D.C., 1954.
4. Jackson, M. L. *Soil Chemical Analysis*, Prentice Hall India, New Delhi, 1967.
5. Kiely, P. V. and Jackson, M. L., *Proc. Soil Sci. Soc. Am.*, 1965, **29**, 159.
6. Marshall, C. E., *The Physical Chemistry and Mineralogy of Soil*, vol. II, John Wiley and Sons, New York, 1977.
7. Choudhari, J. S. and Jain, S. V., *J. Indian Soc. Soil Sci.*, 1979, **27**, 123.
8. Malavolta, E., *Potassium in Agriculture* (ed. Munson, R. D.), American Society of Agronomy, Crop Science Society of America and Soil Science of America, Madison W.I., USA, 1985.
9. Maheshwari, R. K. and Sekhon, G. S., *Clay Res.*, 1985, **4**, 1.
10. Sparks, D. L. and Jardine, P. M., *Soil Sci. Soc. Am. J.*, 1981, **45**, 1094.
11. Sparks, D. L. and Huang, P. M., *Potassium in Agriculture* (ed. Munson, R. D.), American Society of Agronomy, Crop Science Society of America and Soil Science Society of America, Madison, W.I., USA, 1985.
12. Jardine, P. M. and Sparks, D. L., *Soil Sci. Soc. Am. J.*, 1984, **47**, 45.
13. Fanning, D. S. and Keramidas, V. Z., in *Minerals in Soil Environments* (eds. Dixon, J. B and Weed, S. B.), Soil Science Society of America, Madison, W.I., USA, 1977.
14. Huang, P. M., in *Minerals in Soil Environments* (ed. Dixon, J. B and Weed, S. B.), Soil Science Society of America, Madison, W.I., USA, 1977.

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The haplodiploidy threshold and social evolution

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Workers in eusocial insect species help in rearing their siblings and other genetic relatives instead of producing their own offspring. The multiple origins of such eusociality in the Hymenoptera have been ascribed to haplodiploidy because this genetic system makes a female more closely related to her full sisters than she would be to her offspring. To test this so called haplodiploidy hypothesis, I first assume that workers are capable of investing in their sisters and brothers in the ratio that is optimal for them. I then define a *haplodiploidy threshold* as that value of genetic relatedness between workers and their sisters such that they have a weighted average relatedness to the brood they rear of 0.5 and thus have the same fitness as solitary nesting females. Using 177 published estimates of relatedness between sisters in social hymenopteran colonies, I show that in 29 out of 35 species studied, there is not even one estimate of relatedness that is significantly higher than the haplodiploidy threshold. I conclude therefore that the multiple origins of eusociality in the Hymenoptera cannot be ascribed solely to the genetic asymmetry created by haplodiploidy.

EUSOCIAL insects such as termites, ants and many species of bees and wasps exhibit three characteristic features namely, overlap of generations, co-operative brood care and caste differentiation into fertile reproductive castes and sterile worker castes[1,2]. These sterile worker castes present an obvious challenge to Darwin's theory of natural selection[3]. The seminal work of Hamilton[4,5] was the first serious attempt to meet this challenge. Hamilton developed the concept of inclusive fitness and showed that fitness can also be gained by helping genetic relatives in addition to or, indeed, instead of producing offspring.

One reason for the instant appeal of Hamilton's ideas was that the haplodiploid genetic system found in the insect order Hymenoptera creates an asymmetry in genetic relatedness such that full sisters are more closely related to each other (coefficient of genetic relatedness, $r = 0.75$) than a female would be to her offspring, ($r = 0.5$). In the light of this, it is striking that eusociality is known to have arisen at least eleven times independently in the Hymenoptera compared to only twice (once in the termites and once in the naked mole rat) outside that insect order[2,6]. This idea that the genetic asymmetry created by haplodiploidy can promote the evolution of eusociality in the Hymenoptera may be termed the haplodiploidy hypothesis.

There are however at least two hurdles that have to