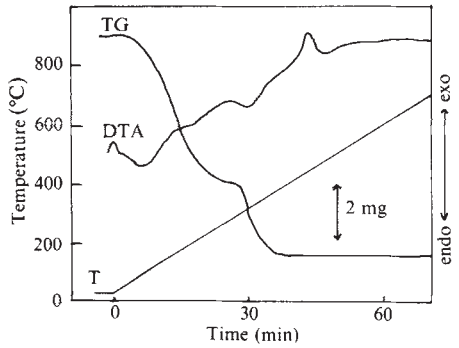

Fig. 2 Infrared spectra of solids I, II and III, recorded using the KBr pellet technique. Transmission has an arbitrary scale. Bands around 3,400 and 1,620 cm^{-1} are due to H_2O in the solid states. Kinks around 2,400 cm^{-1} arise from the influence of CO_2 in the atmosphere.

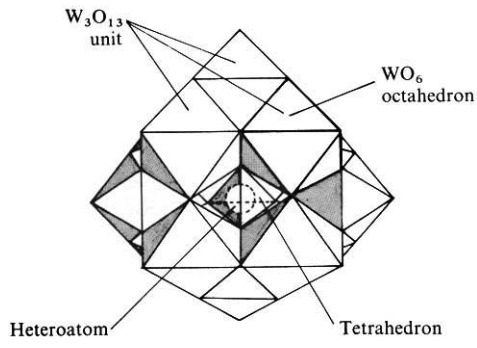

Fig. 3 Schematic structure of heteropolyanion $(XW_{12}O_{40})^{m-}$ with the Keggin structure. A heteroatom such as P is placed in the centre of the tetrahedron, whereas carbon in these compounds may occupy the centre of one of the tetrahedral surfaces.

with common edges) are linked by common corners to give a tetrahedral cavity (Fig. 3). A heteroatom such as P at the centre then provides a tetrahedral PO_4 group with four oxygens for each w_3O_{13} unit. Specific bands due to vibration of the XO_4 group can be seen in infrared and Raman spectra of compounds with this structure.

The infrared band around 1,400 cm^{-1} is, however, distinctive for the present compounds and must be assigned to one of the vibrations due to the C—O bonds (Fig. 2). Although the CO_4 group, the orthocarbonate anion, is formally equivalent to PO_4 or SiO_4, this is an uncommon grouping for carbon which is found only exceptionally in esters such as $C(OCH_3)_4$. Moreover, the vibrational frequencies due to CO_4 are unlikely to appear in the vicinity of 1,400 cm^{-1}.

It is, therefore, more reasonable to suppose that carbon in these compounds is formed into the familiar CO_3 group. An infrared active band (or bands) due to the ν_3 of this planar group is usually found in the range 1,400–1,500 cm^{-1} as, for example, in calcite[7]. From among the vibrational frequencies observed in the infrared and Raman spectra, those which can be assigned to the fundamentals of CO_3 are shown in Table 1. Other bands below 1,000 cm^{-1} are attributed to the WO_6 groups.

The symmetry (D_{3h}) of CO_3 in an isolated state is usually lowered in both the solid state and in solution by interactions with ligands or surrounding molecules, resulting in modified selection rules and/or the splitting of degenerate bands. The two infrared bands at 1,350 and 1,400 cm^{-1} for solid I are due to the splitting of ν_3 at sites of C_s symmetry, but the corresponding frequency is not split in solids II and III, indicating D_3 symmetry. The Raman bands in solids I and II at 950–960 cm^{-1}, which are due to the totally symmetric vibration (ν_1), are Raman-active only in D_3 symmetry and cannot be detected in the infrared spectra of my samples. The frequencies ν_2 of solids II and III are seen at 880–890 cm^{-1} only in the infrared spectra, in agreement with the selection rule. In the case of C_s symmetry, all four vibrations must be active in both infrared and Raman modes, and these bands are indeed found in the spectra of solid I except for the Raman band ν_3, which was presumably not detected because the signals are too weak.

These observations are evidence for the existence of a novel heteropolyacid, $H_4(CW_{12}O_{40})\cdot nH_2O$, based on the anion $(CW_{12}O_{40})^{4-}$ (or, more properly, $(H_2CW_{12}O_{40})^{2-}$ or $(H_3CW_{12}O_{40})^{-}$) which incorporates the CO_3 group. This may be a kind of carbonato-complex in which carbon occupies the centre of one surface of the tetrahedron in the Keggin structure, to give rise to bonds with three oxygens out of four belonging to each W_3O_{13} ligand.

I thank Drs M. Katsumoto, J. Shimada and T. Iwayanagi for helpful discussions.

Received 24 April; accepted 24 May 1984.

1. Pauling, L. *J. Am. chem. Soc.* **51**, 2868–2880 (1929).
2. Keggin, J. F. *Proc. R. Soc.* **A144**, 75–100 (1934).
3. Brown, D. H. *Spectrochim. Acta* **19**, 585–587 (1963).
4. Kurusu, Y. *Bull. chem. Soc. Jap.* **54**, 293–294 (1981).
5. Wada, T. *C.r. hebd. Séanc. Acad. Sci., Paris* **259(C)**, 553–556 (1964).
6. Brown, C. M., Noe-Sperlet, M.-R., Busing, W. R. & Levy, H. A. *Acta crystallogr.* **B33**, 1038–1046 (1977).
7. Nakamoto, K. *Infrared and Raman Spectra of Inorganic and Coordination Compounds* 2nd edn, 98 (Wiley, New York, 1963).

Major ion chemistry of the Ganga–Brahmaputra river systems, India

M. M. Sarin & S. Krishnaswami

Physical Research Laboratory, Navrangpura, Ahmedabad 380 009, India

Rivers are the main pathways by which continental weathering products are transported to the oceans so that the chemistry of river waters and the flux of elements transported by them to the oceans are central to our understanding of the exogenic cycles of elements. There have been several detailed studies of major rivers[1–5] and we now report the major ion chemistry of another, the Ganga–Brahmaputra. These are two of the large rivers which drain the Indian subcontinent and they transport annually ~10^{15} l of water and ~2×10^{15} g suspended matter to the Bay of Bengal[6,7]. On a global scale, these rivers rank fourth in terms of flow, and first in terms of sediment transport[6,7]. Studies on the continental denudation rates and the budgets of major elements in the ocean, would, therefore, be incomplete without good geochemical data on these rivers. Our studies show that the Ganga–Brahmaputra system transports some 118 million tons of dissolved solids annually to the Bay of Bengal and that their water chemistry is dictated by the weathering of carbonates and contributions from soil salts and/or saline groundwaters.

The Ganga originates in the Gangotri glacier in the Kumaun Himalayas and is known as the 'Bhagirathi' at its source. The Alaknanda is the major tributary of the Bhagirathi, and after their confluence at Devprayag the river acquires the name 'Ganga' (Fig. 1). The major tributaries of the Ganga are the Gomti, Ghaghara and Gandak from the north and the Yamuna and Son from the south. The Chambal, Betwa and Ken are the major tributaries of the Yamuna. Although all these rivers are perennial, the peak flow in all of them occurs during the south-west monsoon, July–September. The Brahmaputra originates in the Chamyungdung glacier in the Tibetan Himalayas. Several tributaries join the main river in the Assam valley, a major one being the Manas. The Ganga and the Brahmaputra merge in Bangladesh, before their outfall into the Bay of Bengal.

The Ganga and its tributaries were sampled during three seasons, March, September and December 1982, representing

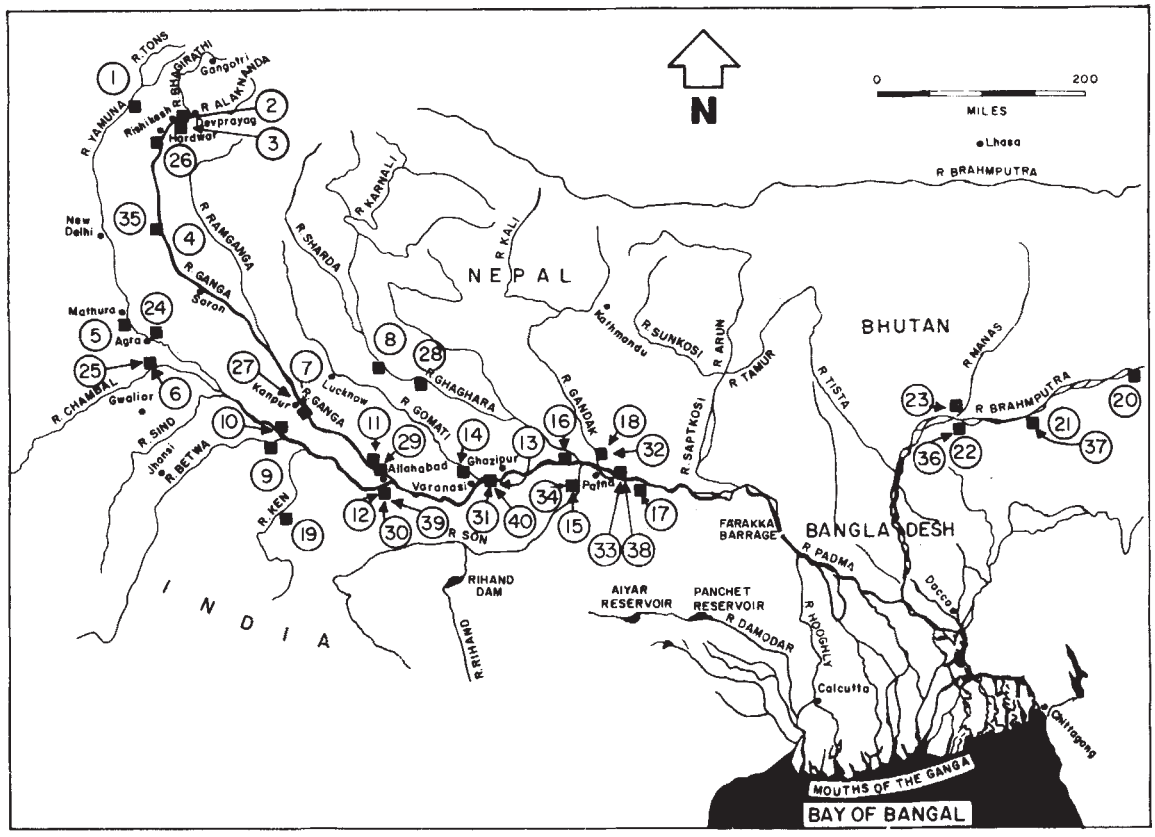

Fig. 1 Sample location map. Numbers correspond to sampling sites in March–April (1–23); September (24–35) and December (36–40) 1982.

Table 1 Major ion composition (μmol l^{-1}) of the Ganga and Brahmaputra rivers and their tributaries

Sample code*	Location	Na	K	Mg	Ca	HCO_3	Cl	SO_4	SiO_2	TDS (mg l^{-1})
Highland rivers										
26, Ganga	Hardwar	59	38	153	353	894	23	121	109	94
28, Ghaghara	Ayodhya	96	59	232	528	1,601	26	76	114	144
32, Gandak	Hajipur	74	84	259	649	1,860	32	103	143	170
22, Brahmaputra	Goalpara	80	46	148	318	884	29	99	118	92
23, Manas	Goalpara	94	42	181	348	930	26	113	131	99
Lowland rivers										
24, Yamuna	Agra	1,401	130	395	794	1,921	1,172	412	170	287
30, Yamuna	Allahabad	556	57	190	547	1,753	222	67	164	173
25, Chambal	Dholpur	593	53	337	829	2,531	284	76	296	247
34, Son	Ara	240	40	166	434	1,372	71	22	210	129
Ganga main channel										
26, Ganga	Hardwar	59	38	153	353	894	23	121	109	94
35, Ganga	Garhmukteshwar	105	68	182	471	1,159	19	143	127	121
27, Ganga	Kanpur	354	82	242	565	1,829	78	103	157	173
29, Ganga	Allahabad	425	79	201	458	1,570	116	85	121	151
31, Ganga	Varanasi	473	62	188	514	1,707	162	72	147	164
33, Ganga	Patna	280	63	203	547	1,707	87	58	129	156

Measurements were taken during peak flow for all rivers (September 1982) except for the Brahmaputra and Manas, for which measurements taken during moderate flow (April 1982).

* Numbers correspond to locations in Fig. 1.

respectively lean, peak and moderate flow conditions. Samples from the Brahmaputra and Manas were collected during April and December 1982 (see Fig. 1 for the sampling sites). All the samples were taken from surface waters, collected from the mid-channel of the river either from highway bridges or by going into the rivers using small boats. Details of sampling and their pretreatment are discussed elsewhere[8]. *p*H, dissolved O_2, conductance and bicarbonate were measured on site. An aliquot of the water sample was filtered within ~6 h of collection through a 0.45-μm Millipore filter using a polycarbonate filter system[8]. The filtered water was split into two fractions, one of which was preserved unacidified and the other acidified to *p*H ~ 2 using HNO_3. The filtered unacidified samples were analysed in the laboratory for major cations and anions using appropriate methods[8]. The major ion composition of the Ganga and its tributaries during their peak flow (samples 24–35; Fig. 1) and that of the Brahmaputra and Manas during their moderate flow (samples 22 and 23; Fig. 1) are given in Table 1. The 'highland rivers' cover the Ganga (up to Hardwar), Ghaghara, Gandak, Brahmaputra and Manas, the 'lowland rivers' the Yamuna (at

Table 2 Average major ion composition (μmol l^{-1}) of the Ganga and Brahmaputra rivers and their tributaries

River	Na	K	Mg	Ca	HCO_3	Cl	SO_4	SiO_2	TDS (mg l^{-1})
Ganga*	533	83	257	475	1,751	146	112	112	170
Ghaghara	131	61	270	562	1,777	29	82	124	159
Gandak	104	85	285	655	1,886	52	130	147	177
Yamuna†	933	62	290	573	2,183	382	120	157	222
Chambal	827	56	374	792	2,627	337	120	260	262
Betwa	2,377	53	690	502	4,238	426	71	237	388
Ken	701	54	461	550	2,683	233	52	214	241
Son	277	43	191	464	1,507	93	27	214	142
Manas	94	42	181	348	930	26	113	131	99
Brahmaputra	92	48	157	351	957	31	106	130	100
Ganga‡	419	67	269	583	1,966	140	83	132	183
World average§	191	38	166	398	1,019	105	96	207	115

See text for calculations of the average composition.
* At Allahabad, before confluence with the Yamuna; † at Allahabad, before confluence with the Ganga; ‡ at Patna, after confluence of the Ghaghara, Son and Gandak; § from ref. 4.

Allahabad), Chambal and Son. For brevity, the results from other seasons are not given here, but they are used to derive the average chemical composition of these river waters (Table 2).

The major ions in river waters are supplied from the atmosphere and from the weathering of rocks/soils in the drainage basin. The atmospheric contribution consists of two components, the marine cycle salts and the terrestrial inputs. Our study did not include the chemical analysis of rain water and thus it is difficult to obtain a precise estimate of the atmospheric supply of major ions to the river waters during the sampling period. However, the atmospheric contribution of marine cycle salts has been estimated from the available rain water data[9], assuming that the measured chloride concentration in the highland rivers, during their peak flow, is solely due to the marine contribution[8]. These calculations suggest that, during peak flow, about 30% of sodium in the highland rivers is of marine origin[8]. Of the lowland rivers, the Son has the largest marine component, 45% Cl and 11% Na. The marine contribution of other major ions to these rivers is negligible. The estimated marine cycle salt contribution is an upper limit in that we have assumed that no chloride is supplied to the river water by weathering processes. That contribution can be taken to be small from the observation that the Cl concentration in highland rivers, during their peak flow (23–32 μmol l^{-1}, Table 1), is very similar to that in rain water from inland stations (18–41 μmol l^{-1}, ref. 8).

In the highland rivers, Ca, Mg and HCO_3 are the most abundant dissolved species in all the seasons sampled. The cations Ca and Mg account for 84–92% of total cations (on an equivalent basis); the (Ca + Mg): (Na + K) ratio ranges between 5.2 and 11.5. HCO_3 constitutes 73–91% of the anions, sulphate accounting for most of the remainder (Tables 1, 2). These abundances favour carbonate weathering as source, which is consistent with the regional lithology of the rivers, whose upper reaches are composed of Siwalik sediments and the limestones, dolomites and calcareous shales of the Deoban–Tejam zone[10,11]. The sulphate in the waters may originate from the weathering of gypsum/anhydrite or by the oxidation of pyrite; in the Kumaun Himalayas, gypsum, has been reported as a common accessory mineral[10] and in the Brahmaputra basin, pyritic sediments are present[4,11]. Furthermore, the low abundance of silica and the high (Ca + Mg): (Na + K) ratios suggest that the contribution of major ions to these waters by silicate weathering has only minor significance.

In the Yamuna (at Allahabad), and the Chambal and Son during peak flow, (Ca + Mg) accounts for 71–81% of the total cations and HCO_3 accounts for 83–92% of the anions (Table 1). As in the highland rivers, the dominance of Ca, Mg and HCO_3 in the major ion composition is attributable to carbonate weathering. The Chambal drains the Vindhyan sandstones, quartzites, siliceous limestones and dolomites, whereas the stretch of the Yamuna between Saharanpur and Allahabad consists of alluvium rich in 'Kankar' carbonates[12]. These three rivers were also sampled during the lean flow season. The water chemistry of the Son shows no significant variation with the seasons. In contrast, in the Yamuna and the Chambal, the major ion ratios differ significantly with the flow conditions[8]. During lean flow, the concentrations of Na, Cl and SO_4 increase considerably and account for nearly a third of the major ions, the alkaline and saline soil salts in the drainage basins and/or effluent seepage of saline groundwaters. The other lowland rivers, the Gomti, Betwa and Ken, were sampled only during lean flow (Table 2). The water chemistries of the Son and Ken are similar. During lean flow, the Betwa waters are very saline and are second only to the Yamuna in terms of the abundance of total dissolved salts (TDS).

Table 3 Average annual fluxes (10^9 mol yr^{-1}) of dissolved species through Ganga–Brahmaputra river system

River	Discharge (10^{12} l yr^{-1})	Na	K	Mg	Ca	HCO_3	Cl	SO_4	SiO_2	TDS (M ton yr^{-1})
Ganga*	59	31	4.9	15	28	103	8.6	6.6	6.6	10
Yamuna	93	87	5.8	27	53	203	36	11	15	21
Chambal	30	25	1.7	11	24	79	10	3.6	7.8	7.8
Ghaghara	94	12	5.8	25	53	168	2.7	7.8	12	15
Son	32	8.9	1.4	6.1	15	48	3	0.9	6.9	4.5
Gandak	52	5.4	4.4	15	34	98	2.7	6.8	7.7	9.2
Ganga†	364	153	24	98	212	716	51	30	48	67
Brahmaputra‡	510	47	24	80	179	488	16	54	66	51
World rivers§	31,400	6,000	1,200	5,200	12,500		3,300	3,000	6,500	3,600

Discharge data from ref. 18.
* At Allahabad before confluence with Yamuna; † At Patna after confluence with Ghaghara, Son and Gandak; ‡ at Goalpara; § from ref. 4.

The downstream and seasonal variations in the major ion chemistry of the Ganga main channel (Table 1) are controlled by the chemistry of its tributaries and their mixing volumes. The (Ca + Mg) : (Na + K) equivalent ratio decreases downstream, but more markedly during lean flow[8,14], when the ratio becomes as low as 1.25 at Varanasi, after the confluence of the Yamuna. The relative increase of (Na + K) during lean flow is attributable to supply from soil salts in the alluvial plains and/or effluent seepage from saline groundwaters. The TDS of the Ganga main channel, during peak flow, range between 94 and 173 mg l^{-1} between Hardwar and Patna (Table 1). The maximum TDS concentration, 401 mg l^{-1}, was observed during lean flow at Varanasi. The TDS concentration and range that we observed in the Ganga main channel, during peak flow, is about a factor of three lower than that reported[15] (227–502 mg l^{-1}) during the wet monsoon in 1977.

The average major ion compositions of the rivers sampled are given in Table 2. For the Ganga and its tributaries, the average concentration, $\bar{C}$, was calculated as $\bar{C} = 0.83\ C_p + 0.17\ C_l$ where C_p and C_l are the concentration of the species during peak and lean flow conditions. The factors 0.83 and 0.17 are based on the monthly discharge data for the Ganga at Farakka[16], which show that 83% of water transport occurs during July–September and the remaining 17% during the rest of the year. The major ion abundances, measured in September and March 1982, are taken to be typical of peak and lean flow conditions. The discharge data for the Brahmaputra at Gauhati[17] show that moderate/peak flow conditions occur during April–October and that 86% of water discharge is during this period. For the Brahmaputra, $\bar{C} = 0.86\ C$ (April) + 0.14 C (December). For the Betwa, Ken and Manas, the measurements were taken during one season only. Although these results are presented as their average composition (Table 2), they are not used for flux calculations.

A comparison of the average chemical composition and the TDS content of the Ganga (at Patna) and the Brahmaputra (at Goalpara) shows that the Ganga waters are nearly twice as saline as those of Brahmaputra (Table 2). Although the water flux of the Ganga is ~70% of that of the Brahmaputra, the annual flux of dissolved salts carried by the Ganga (at Patna), 67 million tons, is ~30% more than that of the Brahmaputra at Goalpara. The Ganga transports nearly three times more Na and Cl than the Brahmaputra. The Na and Cl to the Ganga comes mainly from its tributaries, the Yamuna and the Chambal (Tables 1, 3).

On a global scale, the average TDS content of the Ganga and its tributaries is higher than that of the global mean river water composition (Table 2). The average TDS content of the Ganga (at Patna) is very similar to that of the Chiang Jiang of China[4] and about five times more than that of the Zaire and Amazon[4]. The Ganga accounts for ~2.5% of the global flux of Na to the oceans (Table 3). The Ganga (at Patna) and the Brahmaputra (at Goalpara) together supply ~118 million tons yr^{-1} of dissolved solids to the Bay of Bengal. This accounts for ~3% of the global supply of dissolved salts to the oceans, which is nearly the same as their contribution to the global water discharge.

We thank Drs B. L. K. Somayajulu and W. S. Moore for discussions, and J. P. Bhavsar, N. Hussain, W. S. Moore, P. Sharma and B.L.K Somayajulu for much help during sampling expeditions. Financial support for this study was provided in part by grants from the PL-480 and the Department of Science and Technology to the Physical Reserch Laboratory, and by NSF grants INT-8117218 and INT-8218484 to Dr W. S. Moore.

Received 26 July; accepted 8 October 1984.

1. Reeder, S. W., Hitchon, B. & Levinson, A. A. *Geochim cosmochim. Acta* **36**, 825 (1972).
2. Meyback, M. *Hydrol. Sci. Bull.* **21**, 265 (1976).
3. Meybeck, M. *Neth. J. Sea Res.* **12**, 293 (1978).
4. Hu Ming-hui, Stallard, R. F. & Edmond, J. M. *Nature* **298**, 550-553 (1982).
5. Stallard, R. F. & Edmond, J. M. *J. geophys. Res.* **88**, 9671-9688 (1983).
6. Milliman, J. D. & Meade, R. H. *J. Geol.* **21**, 1 (1983).
7. Holeman, J. N. *Water Resour. Res.* **4**, 737-747 (1968).
8. Sarin, M. M. thesis, Gujarat Univ. (1983).
9. Sequeira, R. & Kelkar, D. *J. appl. Met.* **17**, 7 (1978).
10. Valdiya, K. S. *Geology of the Kumaun Lesser Himalayas* (Wadia Institute of Himalayan Geology, Dehra Dun, 1980).
11. Gannser, A. *Geology of the Himalayas* (Wiley, New York, 1964).
12. Wadia, D. N. *Geology of India* (Tata-McGraw-Hill, New Delhi, 1981).
13. Abrol, I. P. & Bhumbla, D. R. *FAO Soil Resour. Rep.* **41**, 42(1971).
14. Handa, B. K. *Ind. Geohydrol.* **2**, 71 (1972).
15. Subramanian, V. *J. Hydrol.* **44**, 37 (1979).
16. *Discharges of Selected Rivers of the World* (UNESCO, 1964).
17. *Hydrol Rev.* **2**, 8 (1976).
18. Rao, K. L. *India's Water Wealth* Orient-Longman, New Delhi 1975.

Complexity of human T-cell antigen receptor β-chain constant- and variable-region genes

J. E. Sims, A. Tunnacliffe, W. J. Smith & T. H. Rabbitts

MRC Laboratory of Molecular Biology, Hills Road, Cambridge CB2 2QH, UK

Immune systems of vertebrates function via two types of effector cells, B and T cells, which are capable of antigen-specific recognition. The immunoglobulins, which serve as antigen receptors on B cells, have been well characterized with respect to gene structure[1], unlike the T-cell receptors. Recently, cDNA clones thought to correspond to the β-chain locus[2–4] of the human and mouse T-cell receptor have been described. The presumptive β-chain clones detect gene rearrangement specifically in T-cell DNA and show homology with immunoglobulin light chains. The similarity of the T-cell β-chain gene system to the immunoglobulin genes has been further demonstrated by the recent observation of variable- and constant-region gene segments as well as joining segments and putative diversity segments[5,6]. We report here the characterization of cDNA and genomic clones encoding human T-cell receptor β-chain genes. There are two constant-region genes ($C_\beta 1$ and $C_\beta 2$), each capable of rearrangement and expression as RNA. The gene arrangement, analogous to that of mouse β-chain genes[6–8], shows strong evolutionary conservation of the dual C_β gene system in these two species.

The JM cell line, positive for the surface makers T1, T3, T4, T6 and T8 (ref. 9 and unpublished data), was derived from a human acute lymphoblastic T-cell leukaemia patient[10]. A cDNA library of 500 clones was prepared from JM RNA after removing sequences present in the cDNA that were homologous to B-cell mRNA (ref. 3; Fig. 1 legend). Clones encoding T-cell receptor β-chain sequences were isolated from this library in two related experiments. First, we screened a subset of 188 JM cDNA clones with the isolated insert from the mouse β-chain clone 86T1 (ref. 3) and found four hybridizing colonies (pJMT1B10, 4D8, 4F7 and 4H4). Independently, we had been characterizing individual clones in the library by using them as probes on Northern blots containing T- and B-cell RNA. When the isolated insert from one of these T cell-specific clones (clone pJMT1B4) identified in this way was used to screen the same subset of 188 clones, it hybridized to the same four clones identified by the mouse β-chain probe, as well as to another two clones (pJMT4B11 and 4F8). (Clones 1B4, 4B11 and 4F8 fail to hybridize with 86T1 because they do not overlap with it; see Fig. 1.) We conclude that this group of seven clones is probably derived from the β-chain mRNA synthesized in the JM cell line.

The nucleotide sequence of the presumptive β-chain cDNA clones and the derived amino-acid sequence (Fig. 1) show that the clones derive from the homologous human T-cell receptor β-chain, as predicted from their hybridization with the mouse β-chain probe. The 3′ portion of the sequence encodes the constant (C)-region segment (C_β) extending from nucleotide 306 to the termination codon at residue 837, and continues as a presumptive 3′-untranslated sequence. Other sections of the sequence correspond to a joining (J) sequence (nucleotides